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Upper. Phosphoric acid, phosphate, ammonium sulphate, ammonia, and hydrogen plants.
Lower. Zinc and lead smelters and sulphuric acid plants.
The Consolidated Mining and Smelting Co., Trail, B.C.

EFFECT OF SULPHUR DIOXIDE ON VEGETATION

Prepared for

THE ASSOCIATE COMMITTEE ON
TRAIL SMELTER SMOKE

of the

NATIONAL RESEARCH COUNCIL OF CANADA



CANADA

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FOREWORD

The work described in this book was organized in 1929 and was carried on almost continuously for more than eight years. Only the unusual circumstances relating to this case, and in particular the fact that it arose through the carrying out of important industrial operations near an international boundary, made possible so comprehensive an investigation.

The major results of the studies of the Canadian experts engaged in this investigation were printed by the Dominion Department of External Affairs for use in connection with the presentation of evidence to the Trail Smelter Arbitral Tribunal, but the printed reports were not by any means complete from the scientific point of view and were not given wide distribution. The National Research Council has, therefore, decided to make available in book form a series of scientific papers dealing with those phases of the investigation that are of general interest. In so doing, it recognizes the fact that the increasing scale of industrial operations, including both the metallurgical reduction of sulphide ores and the development of heat and power by the use of fuels containing sulphur, has made the problem of smoke and fume disposal one of immediate concern to nearly every country in the world. It is hoped that this contribution of Canadian scientists may assist in the better understanding of that very complex problem.

A. G. L. McNAUGHTON,
President, National Research Council.

Ottawa, Canada,
10 June, 1939.

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ASSOCIATE COMMITTEE ON TRAIL SMELTER SMOKE

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PART I.—FIELD STUDIES

CHAPTER I

INTRODUCTION

BY MORRIS KATZ AND F. E. LATHE

In March, 1929, the National Research Council of Canada was requested by the Department of External Affairs to carry out an investigation in connection with the alleged damage in northern Stevens County, Washington, by sulphur dioxide fumes emitted from the stacks of the Consolidated Mining and Smelting Company at Trail, B.C. At that time the case was in the hands of the International Joint Commission, a reference to this Commission having been made by the Governments of the United States and Canada on August 7, 1928, in accordance with the provisions of Article 9 of the Boundary Waters Treaty of 1909. The following questions were embodied in the terms of reference to the Commission:

1. Extent to which property in the State of Washington has been damaged by fumes from the smelter at Trail, British Columbia.
2. The amount of indemnity which would compensate United States interests in the State of Washington for past damages.
3. Probable effect in Washington of future operations of the smelter.
4. Method of providing adequate indemnity for damages caused by future operations.
5. Any other phase of the problem arising from drifting of fumes on which Commission deems it proper or necessary to report and make recommendations in fairness to all parties concerned.

The investigation undertaken by the National Research Council was at first limited to surveys of field conditions in the area subjected to visitations of sulphur dioxide gas, but, as time went on, the scope of the investigation was enlarged to include a considerable amount of experimental work dealing with the effect of sulphur dioxide on plants, in order to elucidate problems arising from the conditions found in the area.

It is therefore of interest to give a brief account of the operations carried on by the smelter at Trail, and also a history of sulphur dioxide emission, with the abatement measures brought into force in order to reduce the emission.

Operations of the Trail Smelter

The original Trail smelter, built by United States interests in 1896, was acquired in 1906 by the Consolidated Mining and Smelting Company of Canada. Although the smelter originally treated ores from mines of Rossland, B.C., the Sullivan mine at Kimberley, B.C., ultimately became its chief source of supply. In addition to the smelting of the concentrates from the Sullivan mine, a considerable tonnage of custom ores and concentrates is also treated. The production of metals at the Trail plant began to increase during the war with the completion of an electrolytic zinc refining plant in 1916, and during the years 1920 to 1930 there was a seven-fold increase in metal production. This large expansion has been made possible chiefly by the development of successful methods of differen-

tial flotation of the lead-zinc-silver ore of the Sullivan mine (2). In the years 1931 to 1933, owing to the depression, there was a drop in metal production, followed by a further substantial rise. From the point of view of tonnage of non-ferrous metals produced, the works of the Consolidated at Trail, B.C., are believed to be the largest in the world. Official figures of production in 1937 and the total from the beginning of operations to the end of 1937 are shown in Table I.

TABLE I
PRODUCTION OF METALS AND CHEMICALS AT TRAIL B.C.

Metals and chemicals	Year 1937	Total to December 31, 1937	Metals and chemicals	Year 1937	Total to December 31, 1937
	Ounces	Ounces		Short tons	Short tons
Gold	52,435	2,568,477	Bismuth	—	472
Silver	9,846,545	140,007,735	Sulphur	13,533	17,540
	Short tons	Short tons	Sulphuric acid	*132,194	684,141
Copper	2,292	95,380	Ammonium sulphate	57,832	347,207
Lead	206,579	2,452,010	Other fertilizers	44,221	171,113
Zinc	142,650	1,398,471			
Cadmium	218	2,082			

* Most of the sulphuric acid produced is used in the manufacture of fertilizers.

The concentrates from Kimberley are of two types. Lead concentrates average 70.0% lead, 3.7% zinc, and 6.7% iron; zinc concentrates average 51.5% zinc, 3.5% lead, and 11.4% iron.

Both the lead and zinc concentrates are roasted at Trail, and nearly all the sulphur is converted into sulphur dioxide gas during this process. The lead concentrates, mixed with zinc plant residues containing lead and silver, and custom ores, are subjected to a double sintering treatment in Dwight-Lloyd machines. The fumes and gases from this operation are humidified and then passed through Cottrell treaters for the recovery of dust and fumes before going to the 400 ft. stack. The concentration of sulphur dioxide in these gases is about 0.50 to 0.60%.

The sinter is smelted in lead blast furnaces and the bullion refined electrolytically by the Betts process (8), the electrolyte consisting of a solution of hydrofluosilicic acid and lead fluosilicate. Silver, gold, antimony, and bismuth are recovered from the slimes.

The zinc concentrates are subjected to a roasting process in modified Wedge roasters. Here also the fumes pass through flues to a plate type Cottrell plant, leading to a 425 ft. stack. The Company has perfected a special "suspension" roasting process through which the concentration of sulphur dioxide gas has

been increased to about 7%, thus facilitating the conversion of the gas to sulphuric acid.

After roasting, the zinc oxide is treated with sulphuric acid and the zinc recovered by electrolysis. A recent development in zinc and lead metallurgy at Trail has been the installation of a slag-fuming plant, from which about 25% of the zinc output is now being recovered (5).

History of Sulphur Dioxide Emission

The smelter at Trail, B.C., is situated in a valley on the west bank of the Columbia River at a point about eleven miles by river from the International Boundary, or seven miles in a direct line (see map*). The Columbia River here flows in a relatively narrow valley flanked on both sides by mountain ranges that rise to a height of several thousand feet. This constitutes a natural channel for the smelter gases which are confined largely to this valley and drift either to the north in British Columbia towards Castlegar, or southwards in the direction of Northport, Washington, according to the prevailing winds. On occasion the fumes also penetrate up the various tributary valleys of the Columbia. The topography of the Trail area has an important bearing on the problem of dilution of the sulphur dioxide emitted and on the smoke control measures employed in reducing the likelihood of damage to vegetation.

During the early years of the Trail smelter (1900-1904) the quantity of sulphur emitted from the stacks (mostly as sulphur dioxide) was in the neighborhood of 1000 tons per month†. In 1905 and 1906 the emission rose to approximately 1600 tons. Thereafter there was a steady rise in sulphur emission until it reached 2500 tons per month in 1910. A further increase took place during the years 1913 to 1915, and from 1916 to 1919 the average quantity of sulphur emitted per month varied between 4700 and 5000 tons. Some of this increase was due to the emission from the zinc roasters, which began operations in 1916. The annual rate of emission from 1900 to 1935 is shown in Fig. 1.

About 1924 the Company was successful in working out a selective flotation process for the Sullivan ore, whereby the lead and zinc sulphides were more completely separated. At the same time the grade of the concentrates was substantially raised through the elimination of a much greater proportion of iron sulphide in the tailings. The quantity of sulphur rejected is about 1500 tons a day, as compared with 400 tons in the concentrates. In spite of these major technical improvements, however, the production of lead and zinc was increased to such an extent that the rate of emission of sulphur was doubled for the period 1926-1930, when it was maintained at about 9000 to 10,000 tons a month.

The first complaints of damage in northern Stevens County, Washington, coincided with this increase in sulphur emission and with the use of two high stacks erected to serve the enlarged plant. As a result, it was thought by some

* A map of the Columbia River valley is shown in Chapter II, page 25.

† "Ton"=short ton (2000 lb.).

that the great height of the stacks was responsible for the increased area over which sulphur dioxide markings on vegetation could be found.

In 1931 the sulphur emission was reduced to 7000 tons a month, and approximately 1000 tons of sulphur a month was converted into sulphuric acid through the partial operation of remedial works. The following year, with the tonnage of metal smelted reduced in consequence of world market conditions, and also with the full recovery program in operation to convert 30 to 35% of the total sulphur dioxide gas into sulphuric acid, the quantity of sulphur emitted to the atmosphere was reduced to an average of only 3400 tons a month. This emission was less than that in each of the years 1915 to 1924 inclusive, a period during which no complaints were received from the settlers in northern Stevens County, Washington. From 1933 to 1935 a small increase took place with the expanding scale of metal production, followed by a decrease in 1936 and 1937 through the operation of a plant for the recovery of elemental sulphur. Since the early months of 1937 a major decrease has been effected.

Sulphur Dioxide Abatement Measures

Throughout the history of its operations the Company at Trail has taken advantage of the most modern processes and improvements in smelting, giving due consideration to the prevention of smoke nuisances. In the early period of smelter operations heap roasting was practised, but in 1904 furnace roasting was introduced, and in 1914 suspended dust and metallic fumes were removed from the smelter gases by the Cottrell precipitation process.

The original Cottrell plant at Trail was the first commercial installation of its kind in connection with the lead-smelting industry (2). This Cottrell process was by 1919 made still more efficient by the humidification of the gases by means of water sprays. At the present time 93 to 97% of all the fume produced is recovered, so that the quantity of lead and arsenic emitted from the stacks is negligible.

As a result of improvements made in the flotation process at the Sullivan concentrator, the sulphur dioxide emitted to the atmosphere increased only 250% from 1920 to 1930, although metal production increased 700%. By 1935 the quantity of sulphur charged to the furnaces or roasters per unit of metal produced had been reduced to about one-quarter of what it was in 1920.

High Stacks

One of the simplest and most generally accepted methods of preventing damage by sulphur dioxide is to reduce the gas to non-injurious concentrations by dilution. Among the effective dilution measures employed may be mentioned high stacks and hot effluent gases (3).

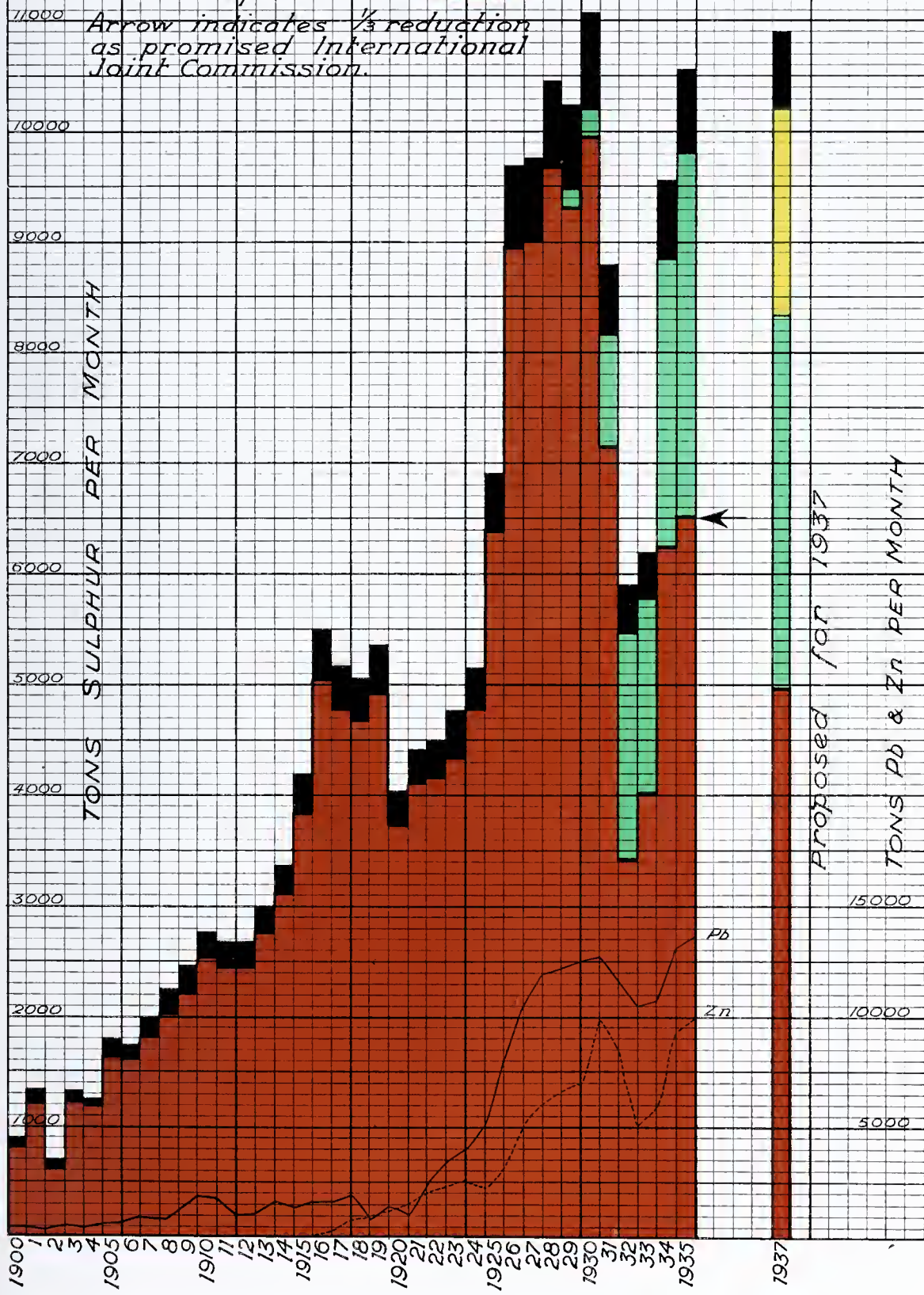
Researches carried out by the American Smelting and Refining Company indicate that, in order to reduce to a minimum the danger of damage to surrounding vegetation, it is essential to discharge the sulphur dioxide from as high

FIG 1

TOTAL TONS SULPHUR CHARGED AND DISTRIBUTED PER MONTH FOR EACH YEAR

- In Slag Calcine etc. (Black)
- Elemental Sulphur (Yellow)
- Sulphuric Acid (Green)
- To Atmosphere (Red)

Arrow indicates $\frac{1}{3}$ reduction as promised International Joint Commission.



PROPOSED FOR 1937

TONS Pb & Zn PER MONTH

a stack as is practicable and at as high a temperature as is metallurgically feasible (6). High stacks have been adopted by all smelters in the United States discharging sulphur dioxide. The necessary stack height depends upon the topography of the country, air currents, and the amount of sulphur dioxide emitted (3). The first high stack at Trail came into operation in November, 1925, and the second in March, 1927.

From experimental work on the effect of stack height on ground concentrations of a given volume of sulphur dioxide, it is clear that, at a given distance from the source, gas emitted from a high stack is more dilute than from a lower stack. This has been verified for distances up to four miles (1, 3). It also holds true for greater distances, but to a lesser extent.

Sulphuric Acid and Fertilizer Plants

In order to cope with the situation which arose as a result of the relatively great quantities of sulphur dioxide emitted from the stacks during the period 1926 to 1930, the Company undertook the construction of remedial works which would reduce by 30 to 35% the amount of sulphur dioxide emitted. This program was submitted to the International Joint Commission and approved by them. As a matter of fact, the Company did not await the recommendation of the International Joint Commission in their report of February 28, 1931, before proceeding with these remedial works, but carried on the erection of these plants during the inquiry, with the object of eliminating injury to vegetation in northern Stevens County at the earliest possible moment. The remedial works, which came into partial operation in 1931 and into full operation early in 1932, consist of three large sulphuric acid plants, each of 112 tons daily capacity, and various fertilizer plants in which the acid is used (4, 7). The operation of the acid plants reduced by 77% the quantity of sulphur dioxide emitted from the zinc plant.

For the manufacture of fertilizers there were installed a phosphoric acid and phosphate plant, and one for the production of ammonia. The ammonia is prepared by high-pressure synthesis from hydrogen and nitrogen, the former being produced by electrolysis of water and the latter by liquefaction of air (4).

Sulphur Recovery

Research by the Company on the concentration of sulphur dioxide from the stack gas by the use of ammonia, with subsequent conversion to elemental sulphur and the formation of ammonium sulphate as a by-product, resulted in the operation of a test plant in 1934. This was followed by a commercial plant costing \$2,500,000. The first unit was started in 1936 and treated all the sulphur dioxide from the zinc stack other than that converted into sulphuric acid. Subsequently various other units were erected for the absorption of tail gas from the sulphuric acid plant and the relatively dilute gas from the lead plant roasters, which contains approximately 0.5% sulphur dioxide. The production of sulphur during 1937 reached about 50 tons daily.

By June, 1937, the total quantity of sulphur recovered by the various remedial works was about 51% of the average emission for the five years, 1926 to 1930. The total expenditures involved in the construction of these plants amounted to about \$15,000,000.

The Weather Plan of Smoke Control

During the last three or four years, in addition to installing their remedial works described above, the Company has adopted the practice of controlling the quantity of sulphur dioxide emitted at any particular time according to the prevailing wind and weather conditions. This was begun in the fall of 1933 and has been continued with increasing success. The scheme was first tried in connection with the waste of sulphur dioxide at the sulphuric acid plants. Prior to that time the operators of these plants paid no attention to wind or weather conditions when wasting sulphur dioxide in excess of that required for the current production of sulphuric acid and fertilizers. Later, the extent of sulphur dioxide emission from the lead and zinc roasters was also controlled. The roasters are operated at a reduced rate, or may be entirely shut down, at such times as the wind, humidity, and temperature conditions are favorable for injury to vegetation. Such periods occur frequently during the growing season, and particularly in the spring, when the wind velocity is low or calm prevails, accompanied by high humidity. It has been found to be perfectly safe to emit all the sulphur dioxide, irrespective of the wind direction, if the wind velocity is high, when dilution is sufficient to render the sulphur dioxide harmless by the time it reaches ground level.

The International Tribunal

A unanimous report was presented by the International Joint Commission in February, 1931, based on the evidence presented by witnesses acting for the Governments of the United States and Canada, and the Company, in which the territory affected by smelter smoke was defined as lying within three zones. Damages up to the end of the year 1931 were assessed at \$350,000, and the Company was asked to continue with the construction of remedial works sufficient to reduce the output of sulphur dioxide to the point where it would do no damage in the United States. It was recommended that scientists be appointed for the purpose of making an investigation to ascertain whether the remedial works undertaken at that time were sufficient to eliminate damage in the State of Washington. The word "damage" was defined as including whatever injuries resulting from sulphur dioxide might be deemed appreciable but did not include such occasional markings as might be caused by the drifting of smoke under unusual atmospheric conditions. However, complaints were made in 1933 and 1934 that damage was still being caused across the International Boundary in the State of Washington, and, the report of the International Joint Commission being unacceptable to the United States, the two governments on April 15, 1935, signed a convention under which they agreed to submit the issues

involved to an International Tribunal for final settlement. This tribunal was required to decide the following questions :

1. Whether damage caused by the Trail Smelter in the State of Washington has occurred since the first day of January 1932, and, if so, what indemnity should be paid therefor?
2. In the event of the answer to the first part of the preceding Question being in the affirmative, whether the Trail Smelter should be required to refrain from causing damage in the State of Washington in the future, and if so, to what extent?
3. In the light of the answer to the preceding Question, what measures or regime, if any, should be adopted or maintained by the Trail Smelter?
4. What indemnity or compensation, if any, should be paid on account of any decision or decisions rendered by the Tribunal pursuant to the next two preceding Questions?

The investigation of smelter smoke injury in Washington, and experimental fumigation work at Summerland, B.C., by the National Research Council of Canada, had been discontinued in the autumn of 1931, and with the exception of measurements of sulphur dioxide concentrations of the atmosphere no further work was carried out until the spring of 1934. At that time the Council was requested by the Department of External Affairs to investigate the claims for alleged damage in Stevens County, Washington, and a survey was made of the claims area. Owing to the nature of the claims made, and the fact that the concentrations of sulphur dioxide occurring in this area had, in the interval, been considerably reduced in magnitude by the operation of the remedial works at Trail, it was found necessary to enlarge the scope of the investigation to include further experimental work, with sulphur dioxide concentrations of a lower order than had been considered previously. During the growing seasons of 1935 and 1936 an intensive study was made of the effect of sulphur dioxide on crops, forests, and soils, and experimental fumigations dealing with crop plants and trees were carried out. The work was brought to an end in 1937, and the evidence gathered was presented before the International Tribunal at its hearings in Ottawa during the period August 23 to October 19, 1937.

In its decision* reported on April 16, 1938, the tribunal submitted an affirmative reply to Question 1 and temporary decisions regarding Questions 2 and 3. It also provided for final decisions on Questions 2 to 4 within three months from October 1, 1940. The tribunal concluded :—

1. That damage in northern Stevens County occurred as early as 1925.
2. That damage to field crops occurred every year from 1932 to 1936, with none in 1937.
3. That damage to orchards during the period 1932 to 1937 had not been proved.
4. That damage to soil through increased acidity was confined to a very small area immediately adjoining the boundary.

*—*The full text of the Tribunal's decision is available from the King's Printer, Ottawa, at twenty-five cents a copy.*

5. That indemnity should be paid on a group of about 40 farms in the vicinity of the boundary on account of a reduction in use or rental value by reason of their location.
6. That there was no evidence of damage to improvements except some slight indication of damage through the corrosion of metals.
7. That slight damage was done to about 200 acres of grazing land immediately adjoining the boundary.
8. That it was not possible to determine whether fumigation had been the cause of soil erosion in the area.
9. That damage was caused to trees in every year from 1932 to 1937, inclusive. Near the boundary, damage was caused over a fairly broad area, but, below Marble*, injury (except to larch in 1936) was confined to the immediate vicinity of the Columbia River.
10. That seed production by trees had not been interfered with except as the trees themselves were damaged.
11. That some reproduction of lodgepole pine, cedar and larch had taken place even close to the boundary.
12. That the damage to cleared and uncleared land other than timber land from January 1, 1932, to October 1, 1937, amounted to \$62,000.
13. That damage to timber for the same period amounted to \$16,000.
14. That there was no evidence of injury to live stock from smelter fumes.
15. That there was no proof of damage to urban property.
16. That there was no proof of damage to business enterprises.
17. That the cost of the United States investigation should not be included in damage caused by the Trail smelter.
18. That no award should be made for "violation of sovereignty".
19. That a temporary regime should be established until October 1, 1940, or such shorter time as might be found necessary.
20. That systematic meteorological observations should be made in the area in question.
21. That from April 25 to May 10, and from June 22 to July 6, 1938, periods of high sensitivity of certain vegetation to sulphur dioxide, not more than 100 tons per day of sulphur should be emitted from the stacks at Trail.
22. That until October 1, 1938, between the hours from sunrise to sunset and with relative humidity of 60% or higher, if the sulphur dioxide concentration in the atmosphere at Columbia Gardens exceeded 1.0 p.p.m. for three consecutive twenty-minute periods, the emission of sulphur should be maintained at not more than five tons per hour until the concentration at Columbia Gardens fell to 0.5 p.p.m.
23. That the cost of maintaining the temporary regime should be borne by the Trail smelter.

*See map, page 25

Scope of the Trail Smelter Smoke Investigation

Organization

The Trail Smelter Smoke Investigation has been carried on under the Associate Committee on Trail Smelter Smoke, which was organized in 1929 by Dr. H. M. Tory, President of the National Research Council, and which functioned under his chairmanship until June, 1935, when he was succeeded in both capacities by Major-General A. G. L. McNaughton. The field work has been carried on mainly by Dr. Morris Katz, of the Division of Chemistry, Dr. G. A. Ledingham, of the Division of Biology, and Mr. A. W. McCallum, of the Dominion Department of Agriculture. Dr. Katz has supervised the chemical investigations and has been in general charge of research in the field under the direction of Dr. G. S. Whitby, Director, Division of Chemistry, and Mr. F. E. Lathe, Director, Division of Research Information. The plant pathological investigations in connection with experimental work and field crop surveys were conducted by Dr. Ledingham. Mr. McCallum carried out the investigations relating to forest pathology in the field and experimental work, and collaborated with Mr. Lathe in studies of diameter increment relating to the growth of trees in the area affected by smelter smoke. Dr. F. A. Wyatt, Professor of Soils at the University of Alberta, collaborated with Dr. Katz in the soil investigations, with the assistance of Dr. H. J. Atkinson, of the Department of Agriculture. Mr. A. Evan Harris, a chemist formerly on the staff of the American Smelting and Refining Company, was appointed to assist in the experimental work and investigation of atmospheric conditions.

In 1929, claims that live stock were being poisoned were investigated by Dr. S. Hadwen, then Professor of Animal Diseases at the University of Saskatchewan.

In the growing seasons of 1929 and 1930, Dr. G. H. Duff, of the University of Toronto, and Mr. M. S. Middleton, of the British Columbia Department of Agriculture, carried out investigations of field crops and orchards, respectively. In later years the investigation of field crops was conducted by Dr. Ledingham, who had assisted Dr. Duff in 1930.

Others who have assisted in the technical investigation and whose names are not mentioned elsewhere in the book include Mr. J. Bickerton, Mr. W. Jack, Dr. R. Morehouse, Mr. H. B. Peto, Dr. D. F. Putnam and Dr. Wm. Ure.

Atmospheric Conditions

A fairly complete picture of the atmospheric conditions in northern Stevens County and the area immediately south of Trail has been obtained by the use of two, and at times three, automatic sulphur dioxide recorders and a portable apparatus. Readings were begun in the fall of 1929, when the emission of sulphur dioxide from the smelter stacks was at a maximum, and have been made continuously every twenty minutes since that time. The automatic instruments were at first placed at points rather far removed from the smelter, but were

later transferred to locations where the gas was likely to be found at more frequent intervals and at higher concentrations. The records obtained revealed in a striking way the effectiveness of the remedial measures already described. They also proved of great value in correlating the symptoms observed on trees, shrubs and crop plants with definite gas visitations and in delimiting zones of damage.

Sulphur Content of Vegetation

The study of atmospheric conditions was supplemented during the greater part of the period by investigations of the sulphur content of vegetation, the principal varieties of conifers and several shrubs being used for this purpose. In the case of the conifers, the needles of the then current and previous two or three years were analyzed separately, since in a smelter area their sulphur content tends to increase from year to year. Controls were obtained from various points well outside the smoke zone; the normal sulphur content for each species was thus established.

By this means it was possible to determine the approximate limits of sulphur dioxide distribution in the atmosphere in each of the years under investigation, both before and after the completion of the remedial works undertaken by the smelter. Studies were made of the relative rates of absorption of sulphur dioxide by conifers during the growing season and winter months, in order to determine whether they might suffer damage under winter conditions. The diminution of sulphur dioxide effect with increased altitude was also studied by collecting samples of vegetation on the slopes of two mountains between Northport, Washington, and the boundary. During one summer alfalfa samples were collected both within and outside the area subjected to sulphur dioxide visitations, and the relation between sulphur and protein content was studied.

Soils

In 1929, work on soils of the Columbia River valley was carried out by Dr. Wyatt, who studied the pH, sulphate content, bacterial activity, and lead and arsenic content of a limited number of samples. In 1930 Dr. Katz determined the pH of a collection of soil samples taken along the Columbia River valley at points increasingly distant from the Trail smelter. More systematic and comprehensive studies were undertaken by these investigators in 1935 and 1936. The main object was to determine the extent, if any, to which the soils of the area had been affected by the operations of the Trail smelter. If sulphur dioxide were absorbed, it would form sulphuric acid, which in turn would dissolve some of the bases from the soils, forming sulphates of calcium, magnesium, and other elements. This process would tend to make the soil increasingly acid and would in time deplete the supply of exchangeable bases.

Water Supplies

The purpose of this investigation was to determine whether, owing to the operations of the Trail smelter, sufficient quantities of sulphates were being

carried into the water supplies to create abnormal conditions in this respect in the areas immediately adjacent to Trail, as well as in those where claims for damages had been made. If sulphur dioxide were being absorbed in appreciable quantities by the soil and rocks of this area, the water leaching through the surface formations would carry down to the rivers, creeks, and other water sources more than the normal quantity of sulphate, and this would be evidence of the depletion of the soil in bases. Another factor considered in this investigation was the influence exerted upon the sulphur content of the water supplies by the composition of the adjacent rock formations.

Forest Studies

A survey of the forests and shrubs of the district in which claims for damage had been made was begun by Mr. McCallum in the summer of 1929. Entomological surveys were carried out by Mr. R. Hopping, entomologist of the Dominion Department of Agriculture. The field investigations were continued up to 1937, with the exception of the years 1932 and 1933. These consisted of surveys made to determine the extent of sulphur dioxide damage on trees and shrubs, as well as the effects of fire, insects, disease, summer drought, and winter injury. Studies were also made of the extent of reproduction and of any possible effect of sulphur dioxide on germination of seed.

In the autumn of 1929 Mr. Lathe and Mr. McCallum began a study of the effect of sulphur dioxide on the diameter increment of Douglas fir, yellow pine and lodgepole pine. This was supplemented by further collections of tree borings in 1930, 1934 and 1936. For comparative purposes a standard trend of growth was established for each species by averaging the annual growth of a large number of trees from locations outside the smoke area.

An attempt was made to determine the extent of the area in which fumes had affected tree growth, yellow pines being used to show the longitudinal limits of the area along the valley of the Columbia River, and Douglas firs to show the lateral limits. A special study was made of precipitation, which, under normal conditions in the area, is the major factor affecting the growth of conifers. The situation was complicated by factors other than fumigation from Trail, and in particular by the operation for some years of a smelter at Northport, near the centre of the area in which damages were claimed.

Fumigation of Conifers

In the autumn of 1930, arrangements were made to conduct experiments at the Dominion Experimental Station, Summerland, B.C., on the effect of sulphur dioxide on conifers. The work was undertaken in order to elucidate some of the problems encountered in studying the condition of trees in the area subjected to visitations of gas from the Trail smelter. Douglas fir and yellow pine trees growing under natural conditions were treated with sulphur dioxide over a wide range of concentrations. During the fumigations the environmental conditions in the cabinets were maintained as nearly identical as possible with

those existing outside, air being constantly supplied, and continuous automatic measurements being made of the sulphur dioxide concentrations at the inlet and exit ends of the cabinets. In 1934 the fumigated plots of trees were examined for residual effect as a result of the gas treatment; a study of the height growth was carried out in 1935.

In view of the possibility that transplanted conifers might not react to fumigations with sulphur dioxide in the same manner as trees growing vigorously in their natural habitat, experiments were carried out in 1935 and 1936 on transplanted stock, six varieties of conifers being used. Of special interest were fumigations of larch trees, which had been observed to be extremely sensitive to sulphur dioxide during the early part of the growing season in the Northport area, but which nevertheless grow closer to the smelter than any other conifers.

Crop Surveys

Owing to the mountainous character of the Northport area, only a very small portion of the land is suitable for agricultural purposes. The farms lie on benches or terraces east or west of the Columbia River and along tributary creeks. The terraces along the Columbia River consist for the most part of light sandy soils of low water-holding capacity. Those along the tributary creeks are generally composed of much better soils of a sandy loam or clay loam type with occasionally muck or peat predominating.

Crop surveys dealt with the distribution of sulphur dioxide markings, the determination of crop damage, and the identification of various diseases prevalent in the area. Studies were made of markings caused by sulphur dioxide and of discolorations on plants caused by insects, fungi, and physiological disorders. The yellow top disease of alfalfa received a great deal of attention, since the claimants in the area attributed this condition to gas fumigations, and a difference of opinion existed among plant pathologists as to the relation of this chlorosis to the presence of sulphur dioxide in the air.

The gas records of the automatic sulphur dioxide recorders, showing the character and extent of the smoke visitations from the Trail smelter, were found to be of great value in determining damage to field crops. Whenever it was possible to do so, a survey of certain farms in the area was made after each major fumigation, and the symptoms observed on plants were correlated with the sulphur dioxide concentrations reported.

Beginning in 1930, experimental plots were maintained beside one of the recorders, and thus a complete history of the duration and concentration of sulphur dioxide to which these plants were subjected became available. Observations on the condition of the plots were made almost daily, so that it was possible to note even the slightest occurrence of sulphur dioxide markings.

Fumigation Experiments on Crop Plants

During four summers, experiments were carried out at Summerland, B.C., on the effect on barley and alfalfa of sulphur dioxide concentrations of a lower order of magnitude than that usually mentioned in the literature in connection with fumigation experiments. The entire range of concentrations found in the Trail smoke area was explored. Special attention was given the elucidation of problems arising in connection with the field crop surveys in the smoke area, such as the classification and diagnosis of various types of sulphur dioxide injury, the influence of certain environmental factors on susceptibility, and the effect, on yield, of fumigations causing a definite percentage of injury, as well as those causing no visible injury. The chemical phases of the investigation dealt with the mechanism of sulphur dioxide absorption in leaves and the effect on sulphur, nitrogen and carbohydrates of leaves and grain.

The yield studies were carried out on plots treated at various stages of growth, the weights being taken at maturity. Some of the experimental treatments consisted of single fumigations, while in others the plants were fumigated repeatedly, or continuously for long periods.

Studies were made of the rate of carbon dioxide assimilation by alfalfa in the presence of sulphur dioxide in concentrations covering the entire range of those likely to be found in industrial areas, in order to determine any effect, no matter how small, on crop plants. By this means it was possible to determine effects that would have escaped detection by any other method.

The theory of "invisible injury" was investigated by means of yield tests and studies of the rate of carbon dioxide assimilation. These were carried out with crops grown to maturity during treatment with sulphur dioxide in concentrations lower than the threshold value for visible injury.

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CHAPTER II.

**SULPHUR DIOXIDE IN THE ATMOSPHERE OF
INDUSTRIAL AREAS**

BY MORRIS KATZ

Introduction

The discharge of waste gases into the atmosphere is an acute problem wherever large quantities of coal are utilized in industrial processes or where metallurgical operations involving the smelting of sulphur-containing ores are carried on adjacent to agricultural or forest areas.

In industrial regions where large quantities of soft coal in particular are consumed there are discharged into the atmosphere huge quantities of soot and tarry substances, in addition to the various gaseous products of combustion, and it has been shown that the unflourishing condition of vegetation, particularly conifers, in such areas is due more often to soot than to sulphur dioxide. Cohen and Ruston (3) show that soot and other solid impurities cause a diminution in growth by reducing the photosynthesis of the leaf surface. The stomata of the leaves become clogged with these solid particles and normal gaseous exchange is hindered.

Within recent years the annual consumption of bituminous coal in New York city has been approximately 10 million tons, and that of anthracite virtually the same. If the average sulphur content of the coal were 1.5%, the amount of sulphur discharged annually from these two sources alone would be 300,000 tons. The sulphur dioxide from fuel oil consumed in this area would add appreciably to this total. In Detroit the annual consumption of bituminous coal is from 8 to 9 million tons, greater Cleveland 4.5 to 5 million tons, St. Louis 5 to 6 million, Cincinnati 2.2 million, Milwaukee 3.5 million, and Minneapolis 1.2 million tons.

Philadelphia consumes about 3 million tons of anthracite coal annually. The coal consumption by public utility companies in Cook county, Illinois, in 1929 was 3,380,269 tons (4). If the average sulphur content of Illinois and Indiana coals (4) were 3%, the quantity of sulphur dioxide emitted daily from power plants in this district would be 493 tons. In the United States, coals containing 3 to 5% of sulphur are quite commonly used in power stations, whereas in England coal containing 2 to 3% sulphur is likely to be increasingly necessary in the future (18).

It has been estimated that the total consumption of coal in the United Kingdom is about 132 million tons (long), of which 100 million tons represent the factory consumption (3). In the Ruhr industrial region there was a daily emission of 373 tons of sulphur dioxide from coke works alone during August 1927 (11). To this must be added the emission from blast furnaces, smelters, rolling mills, and other great industrial plants in this region.

Smelters cause damage principally because of the discharge of abnormal quantities of sulphur dioxide. The emission of this gas from a smelter in the United States, which at one time treated 10,000 tons of ore per day and produced one-sixth of the world's supply of copper, reached the figure of more than 2,000 tons per day (25). J. K. Haywood reports that a smelter operating at Redding, Cal., in 1907, discharged daily about 748 tons of sulphur dioxide (9). A considerable amount of sulphur dioxide is discharged in the smelter districts of Salt Lake, Utah, St. Louis, Mo., Anaconda, Mont., and Arizona. In the Salt Lake district, in 1933 a depression year, the sulphur dioxide produced from three smelters amounted to 223,594 tons, of which only 10,000 tons was recovered and converted to sulphuric acid (19). In the same year the emission from the Trail smelter amounted to 96,000 tons, while approximately 42,600 tons of sulphur dioxide was recovered and converted to sulphuric acid.

Table I indicates the annual amount of sulphur charged to the furnaces and that discharged to the atmosphere since 1924 at the Trail smelter. It will be noted that the emission of sulphur to the atmosphere increased during the period 1924 to 1930 with the rise in quantity of sulphur charged to furnaces or increase in amount of ore smelted. From 1931 to 1936 there has been a considerable reduction in the amount of sulphur emitted to the atmosphere owing to the installation of sulphuric acid units to recover a part of the sulphur dioxide.

TABLE I
ANNUAL EMISSION OF SULPHUR DIOXIDE AT TRAIL, B.C.

Year	Sulphur charged to furnaces, thousands of tons	Sulphur emitted to atmosphere, thousands of tons	Average daily sulphur emission, tons	Sulphur emitted in per cent of sulphur charged
1924	61	58	159	95.0
1925	83	77	211	92.7
1926	118	108	296	91.5
1927	118	109	298	92.3
1928	125	116	318	92.8
1929	123	112	307	91.0
1930	133	120	328	90.2
1931	105	85	233	80.9
1932	70.5	41	112	58.2
1933	74.5	49	134	65.8
1934	114	75	206	65.8
1935	127	78	214	61.4
1936	128	73	200	57.0

Literature Review

Sulphur Dioxide Conditions in Smelter and Urban Areas

The following review indicates the sulphur dioxide conditions in some of the more important smelter and urban areas for which data are available in the literature.

According to Ellis the early investigations of R. Angus Smith indicate that in various localities in the vicinity of London, England, in November 1869, the

air contained sulphur dioxide in concentrations which varied from 0.26 to 0.63 p.p.m. by volume, with values as high as 1.70 to 2.83 p.p.m. in the vicinity of the Metropolitan Railway (7).

Ladureau (12) in 1883 found 1.80 to 2.00 p.p.m. of sulphur dioxide in the air of Lille on calm days and a lower concentration of 1.40 p.p.m. on stormy days.

Wieler (32) has determined gas concentrations of 0.53 to 4.63 p.p.m. in Probstey Forest at various distances up to 2.4 kilometres from the smoke source. In the same forest at a distance of 10.25 kilometres from the stack Rippert (21) found concentrations of 0.04 to 0.60 p.p.m. Concentrations varying from 0.16 to 2.16 p.p.m. were also found in the vicinity of various coke ovens and chemical plants.

An extensive investigation of atmospheric pollution was carried out by the Selby Smelter Commission in 1915 (10). In the vicinity of the Selby smelter, of 4,862 tests, 75% indicated less than 0.20 p.p.m.; 86% indicated less than 0.40 p.p.m. and more than 97% indicated less than 1.00 p.p.m. of sulphur dioxide. Only 0.43% of the total number of test samples contained more than 2.00 p.p.m. and the maximum analyzed was 7.10 p.p.m. The average concentration was 0.22 p.p.m.

In the business section of San Francisco during calm mornings, the concentration of sulphur dioxide was found to be as high as 1.80 p.p.m. Under brisk wind conditions, the sulphur dioxide content was seldom more than 0.20 p.p.m. One hundred and three determinations made in the vicinity of Richmond, Cal., contiguous to an oil refinery, showed an average value of 1.10 p.p.m. In Martinez, Cal., and vicinity, 168 determinations yielded an average of 0.23 p.p.m., the maximum being 1.70 p.p.m. In Oakland and Berkeley, Cal., the maximum of 148 determinations was 1.00 p.p.m.

An investigation carried out in the Salt Lake valley in the vicinity of the Murray and Midvale smelters, from April to September, 1920, indicated that the atmospheric conditions at the ground level within three miles of each smelter in the line of the smoke stream, as reported by Swain (26), were as follows:—

	Murray	Midvale
Total tests, number	4386	4311
Av. conc., all tests, p.p.m. SO ₂	0.28	0.49
Max. " " " " "	7.6	19.4
" hourly av. conc., " "	1.07	2.78
% total tests over 6 p.p.m. "	0.02	0.65
" " " " 3 " "	0.36	3.5
" " " " 1 " "	5.2	10.2
" " " negative	42.1	43.9

An investigation carried out by the U.S. Bureau of Mines during the winter of 1919 to 1920 in Salt Lake City indicated an average concentration of 0.15

p.p.m., during December and January, with a maximum of 0.80 p.p.m., whereas in March the maximum concentration was 0.40 and the average 0.01 p.p.m. (17).

Determinations of the sulphur dioxide content of the air carried out in every month of the year 1929 to 1930, at Prague, indicated an average concentration of 0.35 p.p.m. during the month of February; this dropped to 0.017 p.p.m. in May and increased again to 0.103 in the period November to January (13).

Reynolds (20) reports that in the vicinity of London during a week in the winter that included a good deal of fog, the concentrations rose to over 0.40 p.p.m., whereas in the summer they fell at times to 0.08 p.p.m. He noted a sudden fall of considerable magnitude in the concentrations during periods in the winter when factory chimneys were least active and while domestic combustion was probably at its height. Extensive studies have been undertaken by the Department of Scientific and Industrial Research of Great Britain on the condition of the atmosphere in several large industrial cities (5, 6). Data taken from the 18th and 19th annual reports on the "Investigation of Atmospheric Pollution", for the years ending March 31, 1932 and 1933, are of interest. At Barnsley, the highest reading reported was 1.50 p.p.m., with an average concentration of 0.423 p.p.m. in November, 1931; and at Birmingham, the maximum concentration found was 0.366 p.p.m. in December, with an average of 0.113 p.p.m. The highest concentration found in the London district during this two-year period was 0.54 p.p.m. At Sheffield there was reported a maximum concentration of 0.93 p.p.m. with an average of 0.228 in December, 1931, whereas at Newcastle-on-Tyne a maximum concentration of 2.06 p.p.m. with an average of 0.66 p.p.m. was found in March, 1933.

A considerable number of data have been reported dealing with atmospheric pollution at Pittsburgh. Tests carried out during the year July, 1931, to June, 1932, at the Pittsburgh Testing Laboratories (2), in a thickly populated district, indicated that high sulphur dioxide readings invariably coincided with low wind velocities, especially when smoke and fog were present. The average sulphur dioxide concentration for the entire year was 0.30 p.p.m. and the maximum concentration of 2.50 p.p.m. was attained on two occasions. The monthly average concentration varied between 0.12 and 0.51 p.p.m., whereas for a period of more than seven hours on one day the concentration was 0.80 p.p.m. or over. Maximum concentrations between 1.10 and 2.50 p.p.m. were noted on 9% of the days, whereas those between 0.60 and 1.00 p.p.m. were observed on 11.8% of the days covered by the tests. Schade (22), sampling air on a roof 163 ft. above the ground in Pittsburgh, as part of the program of the Mellon Institute on air pollution, found that during the year 1932 the average concentration was 0.14 p.p.m. sulphur dioxide, with a maximum of 1.10 p.p.m., the monthly average indices varying from 0.06 to 0.21 p.p.m. At the breathing level on a congested street corner, average concentrations were found to be three times as high as those in the samples taken on the roof. In the same paper a comparison is given of the results obtained by the U.S. Bureau of Mines, Pittsburgh

Testing Laboratories, and the Mellon Institute. It is concluded that if allowance is made for the differences in sampling height and distance from the source of pollution at the three different stations, all the results are in general agreement. The highest readings were obtained at the Pittsburgh Testing Laboratories, whereas the data of the U.S. Bureau of Mines were of the same order as those of the Mellon Institute.

More recently, since the latter part of August, 1936, the Mellon Institute has been engaged in an investigation of concentrations of volatile sulphur compounds in the atmosphere within a radius of 25 or 30 miles of some of the larger cities of the United States. The areas in which measurements are being made regularly are Pittsburgh, Philadelphia-Camden, Washington, D.C., St. Louis-East St. Louis, and Detroit, as well as in the 0 to 5 mile zone of other industrial areas (16). During the heating season from October 12, 1936, to April 25, 1937, a total of 20,700 individual tests were made. The highest concentrations of sulphur dioxide found in this survey were in the St. Louis-East St. Louis district, the maximum in the zone of 0 to 5 miles' radius being 2.266 p.p.m., and the average 0.261 p.p.m. The average of all the readings in the 0 to 15 mile zone was 0.180 p.p.m., and in the 0 to 30 mile zone 0.147 p.p.m. The highest concentration found in the Pittsburgh district was 1.007 p.p.m., whereas the average and maximum concentrations in the Philadelphia-Camden and Detroit areas were considerably lower than those in the St. Louis and Pittsburgh areas. At Chicago, during a period of four days in December, when 80 tests were made, the maximum concentration was found to be 0.402 p.p.m. and the average 0.109 p.p.m., while during the period March 25 to April 23, 954 tests indicated a maximum concentration of 0.549 p.p.m. and an average of 0.073 p.p.m. Appreciable concentrations of sulphur dioxide were found in all the industrial as well as in the residential areas covered by this survey.

Recently Setterstrom and Zimmerman (23) have shown that measurable concentrations of sulphur dioxide prevail in the atmosphere at Boyce Thompson Institute, Yonkers, New York. Continuous records over a period of one year show a maximum of 0.75 p.p.m. and an average, including zero readings, of 0.033 p.p.m., with gas present 62.2% of the time in concentrations of 0.01 p.p.m. and over.

Smoke Abatement

The contamination of the atmosphere through the discharge of smoke containing noxious products of combustion which may be harmful to plant life, has led to an aroused public opinion. Various smoke abatement investigations have been instituted to improve smoke conditions, and regulations have been enacted to curtail the amount of injurious products that may be emitted from stacks. Wherever such smoke abatement measures have been successfully undertaken there has been a noticeable diminution in the prevalence of fogs, which tend to form when the atmosphere is highly charged with solid impurities during periods of high humidity.

With regard to sulphur dioxide abatement measures in Great Britain, most sources of sulphur dioxide emission come within the scope of "The Alkali Works Regulation Act" of 1906, and the extensions of this act in 1928 to 1935. A rigid inspection program is maintained and many works are subject to specific limitations in regard to the emission of noxious gases or dusts. Those works in which sulphide ores are calcined or smelted may, if damage is being caused, be ordered to limit the amount of noxious gases emitted to the atmosphere, wherever such corrective measures may be adopted at reasonable cost.

The measures adopted to reduce the sulphur dioxide emission from smelting plants to non-injurious concentrations usually fall under two classes: (a) dilution and removal of the gas by air currents, and (b) recovery of the sulphur dioxide as liquid sulphur dioxide, in the form of elemental sulphur, or by oxidation to sulphuric acid. Dilution measures are adopted wherever it is not practicable to recover the sulphur dioxide. In the case of a number of smelters in the United States, control by dilution has been found effective in reducing concentrations of sulphur dioxide to the point where it does no damage to vegetation. The measures adopted are the erection of high stacks, heating the stack gases and so operating the plants according to wind and weather conditions as to obtain the maximum amount of dilution in relation to the quantities of sulphur emitted. Such measures have been found quite effective in the Salt Lake smelting district, at Tacoma, Wash., and elsewhere.

In some smelters in Great Britain the sulphur content of the discharged gases is lowered by the use of a water or alkali scrubber, but such processes are likely to be quite expensive because the recovered products are not marketable.

R. S. Dean, in a recent publication of the U.S. Bureau of Mines, reviewed various processes of sulphur recovery (4). When the concentration of sulphur dioxide in metallurgical stack gases exceeds 2%, it is practicable (but may not be economically feasible) to recover the sulphur dioxide either by direct reduction to sulphur or oxidation to sulphuric acid.

The methods developed by Imperial Chemical Industries, and also the Lurgi and Guggenheim processes, involve an additional concentration step in the case of smelter gases that are too dilute to permit of direct reduction to sulphur. The Imperial Chemical Industries' process for concentration is based on the use of a basic aluminium sulphate solution as the absorption medium.

Pearson, Nonhebel and Ulander (18) describe the removal of smoke and acid gas from flue gases by means of a non-effluent water process developed by Imperial Chemical Industries, using vertical counter-current absorption towers. The sulphur dioxide saturated liquor is regenerated by heating to expel sulphur dioxide, and the sulphur trioxide formed by oxidation removed by the addition of ammonium sulphate and lime.

The Lurgi process involves the use of a xylidine water mixture for absorption of the sulphur dioxide (31). The absorbed sulphur dioxide is regenerated by

heating the mixture to 80 to 100°C., and the xyloidine recovered. It is desirable during this absorption process to prevent as much as possible any oxidation of the sulphur dioxide to sulphate.

According to Dean (4), the Guggenheim process utilizes a solution of ammonium sulphite as the absorbing medium for sulphur dioxide with the formation of ammonium bisulphite. On heating the ammonium bisulphite, sulphur dioxide is given off and the sulphite is regenerated. Ammonium sulphate crystals are formed during the absorption and must be filtered off from the absorbent at intervals and the ammonia regenerated by treatment with lime. This process was operated on a pilot-plant scale, converter gas containing 6 to 7% sulphur dioxide being used.

In the sulphur dioxide concentration process used with the lead stack gas at Trail, B.C., a similar absorption system is used but the sulphur dioxide is recovered by treating the ammonium bisulphite with sulphuric acid, rather than by heating it. The ammonium sulphate formed in this process is a valuable by-product (14). The concentrated sulphur dioxide obtained is reduced to sulphur by passing it through a heated coke bed in a vertical reduction furnace. The sulphur dioxide mixed with the required amount of air is passed through the reduction chamber at such a rate that a substantial amount of sulphur dioxide remains undecomposed. The sulphur is then condensed and the exit gases are returned to the absorption system (4).

An account of the measures adopted by the Consolidated Mining and Smelting Company at Trail, B.C. to reduce the concentrations of sulphur dioxide in the air and the emission from their stacks has already been given in Chapter I. All the known methods of coping with this problem have been tried, including the erection of stacks approximately 400 ft. high at both the lead and zinc smelters, the erection of sulphuric acid works having a total daily capacity of about 375 tons and a sulphur recovery plant with a present capacity of about 70 tons. The result of these efforts has been a reduction of about 57% in total sulphur emission. It is now believed that these efforts have eliminated the possibility of further damage in northeastern Stevens County, Wash., and there has already been noted a marked improvement in the appearance of the vegetation in the area previously affected by the smelter gases. The significance of the gas concentrations found in this area in relation to plant growth is discussed in later chapters.

Methods of Determining Sulphur Dioxide in Air

The early methods for determining the concentration of sulphur dioxide in air were more adapted for flue gas analysis than for the low concentrations ordinarily found in urban and smelter areas. The first method adapted to the rapid determination of small amounts of sulphur dioxide in air was that used by Marston and Wells in the investigation carried out by the Selby Smelter Commission (10). Measured volumes of air were drawn into a partly evacu-

ated 24-litre aspirator bottle. A definite amount of starch solution containing sufficient iodine to bring the reagent to a desired blue color was added, and the aspirator bottle was then shaken vigorously so as to bring the air sample in contact with the starch-iodine solution. The color of the partly bleached iodine solution was then restored by the addition of standard iodine reagent so as to match that of a blank similarly treated. Reasonably close checks were obtained against known mixtures of sulphur dioxide in air in the range of 0.80 to 3.00 p.p.m. With lower or higher concentrations the errors were as high as 20 to 25%. This method, with certain modifications, was used by Monnett (17) in his survey of atmospheric conditions at Salt Lake City, in the investigation by the Swain Commission (26), and later by McKay and Ackermann (15).

A distinct advance over the method of Marston and Wells was made by Thomas (28), who developed not only a portable apparatus for the rapid measurement of small concentrations of sulphur dioxide in air but also a continuous automatic method which has become widely used in recent years. Thomas investigated the stability and efficiency of iodine solutions for absorbing sulphur dioxide. When 28 litres of pure air was aspirated through 100 cc. of 0.0011 *N* iodine solution, containing 2 gm. of potassium iodide and 1 gm. of starch per litre, the loss of iodine was about 4%. Only about half of this material was caught in the second absorber. A 0.0006 *N* solution was changed only about 1% by this treatment and more dilute solutions were quite stable. A 0.000075 *N* solution did not change when 400 litres of air was drawn through it.

The iodine method advocated by Thomas involves the use of an absorbing solution of 0.0005 *N* iodine, containing 1 gm. of starch and 2 gm. of potassium iodide per litre. After aspiration with the required amount of air at the rate of about 10 litres per minute the iodine solution is titrated with *N*/500 sodium thiosulphate solution. In his first paper on this subject, Thomas describes a semi-automatic apparatus for the determination of low concentrations of sulphur dioxide in air, iodine solutions of the above type being used. The method is applicable over the range of concentrations from 0.10 to 60 p.p.m.

Ellis (7) describes two methods for the determination of concentrations of sulphur dioxide in air. The first method, which is used for measuring the titratable acidity of the air, utilizes a solution of hyperol, the solid compound of hydrogen peroxide with urea, in water.

The second method described by Ellis (7) for the determination of sulphur dioxide, using iodine, potassium iodide, and starch solution as the absorbent, is identical with that advocated by Thomas and Cross. Ellis states that *N*/2000 iodine solution containing potassium iodide to the extent of 2 gm. per litre was remarkably stable and he is of the opinion that the dissipation, even in the dark, of the approximately 0.0003 *N* iodine solutions, recorded in the case of the method of Marston and Wells, is due to the absence of sufficient potassium iodide. Furthermore, he found that *N*/500 thiosulphate solution, when care-

fully made up, maintained its concentration unchanged during a period of 37 days, whereas that of an arsenite solution dropped progressively during this period. All solutions were kept in the dark when not in use.

The preparation of stable iodine solutions is quite important in methods of this type, since a rapid stream of pure air passed through an aqueous iodine solution will soon weaken the strength of the solution. If, on the other hand, the vapor pressure of the iodine in solution is repressed by the addition of potassium iodide and starch, solutions may be made that are remarkably stable even after prolonged aspiration with air. Zepf and Vetter (33) investigated the stability of very dilute iodine solutions and showed that a certain minimum quantity of both starch and iodine was necessary to eliminate loss from a $N/10000$ iodine solution.

A method described by Smith and Friis (24) consists in absorbing the sulphur dioxide in 50 cc. of $N/10$ sodium hydroxide. The sodium hydroxide solution is then neutralized with 6 cc. of N hydrochloric acid and 1 cc. of starch solution. It is then titrated with $N/1000$ iodine solution, the iodine being added until a blue end-point is reached. A comparison is made with a blank determination, carried out to a similar end-point.

The apparatus, which is portable, is compact and can be conveniently mounted in an automobile. The volume of air aspirated through the solution is measured by means of a calibrated flowmeter. This method was used with good results by the Mellon Institute in their recent survey of the air in various industrial centres.

The method used by the writer in measuring sulphur dioxide concentrations with a portable apparatus in the Trail area, and also in the Windsor-Detroit area, is based on that of Thomas and Cross (28), with the modification by S. W. Griffin involving the use of a soda lime tower in connection with the blank determinations (8). The apparatus consists of an accurately calibrated flowmeter connected to two absorbers of 350 cc. capacity. The flowmeter and absorbers with the appropriate stopcock connections, two 100 cc. automatic pipettes for measuring out the exact volume of absorbent, an accurate micro-burette of 10 cc. capacity, for titrating the aspirated solutions, a thermometer, and portable barometer are mounted in a small wooden box. Suction is obtained by attaching this apparatus to the exhaust manifold of the automobile in which the equipment is transported, a small surge tank, equipped with needle valves, being placed between the portable apparatus and the connection to the exhaust manifold. A small electrically driven pump may also be used as a source of suction. The absorbing solution is aspirated with air at a rate of about 10 to 15 litres per minute, and while the contents of one absorber is titrated, the second one may be aspirated, so that measurements of the air are made almost continuously, the time taken for a single determination being usually about six to eight minutes. The flowmeter consists of a small length of capillary tubing connected to a U-tube and calibrated according to the method advocated by

Benton (1), calibration being effected over the range of 4 to 30 litres per minute.

The solutions used are $N/1000$ standard iodine containing 2 gm. of potassium iodide per litre, $N/1000$ to $N/750$ sodium thiosulphate, and a dilute iodine-starch solution as absorbent. The sodium thiosulphate reagent may be standardized against a $N/500$ potassium dichromate solution or alternatively the $N/1000$ iodine is standardized with an accurately prepared arsenious oxide solution. The iodine-starch solution used in absorbing the sulphur dioxide is made up as follows: 45 to 50 cc. of the above-mentioned standard iodine solution, $N/1000$, and 2 gm. of potassium iodide are dissolved in distilled water; 500 cc. of a freshly prepared starch solution, containing 2 gm. of starch, is added and the whole made up to 1 litre. A portion (100 cc.) of this solution is used for each test and, after being aspirated with the required amount of air, is titrated with the standard sodium thiosulphate solution to a light blue color. The end-point is compared with that of the blank determination carried out with 100 cc. of iodine-starch solution aspirated with an equivalent of sulphur-dioxide-free air. In the field a blank determination is carried out after a series of about 5 to 10 tests, the inlet end of the sampling tube being attached to a small soda lime tower, in order to render the air sulphur-dioxide-free.

The concentration of sulphur dioxide in the atmosphere is determined as follows:

$$\begin{aligned} 1 \text{ cc. of } N/1000 \text{ thiosulphate} &= 0.032 \text{ mg. SO}_2 \\ &= 0.0112 \text{ cc. SO}_2 \text{ at } 0^\circ\text{C and } 760 \text{ mm.} \\ 0.0112 \times \left\{ \begin{array}{l} \text{cc. } N/1000 \\ \text{thiosulphate for blank} \end{array} \right. &- \left\{ \begin{array}{l} \text{cc. } N/1000 \text{ thiosulphate} \\ \text{for test} \end{array} \right. \Bigg\} \times 10^6 \\ \text{p.p.m. SO}_2 &= \frac{\quad}{\text{Volume of air sample at } 0^\circ\text{C. and } 760 \text{ mm.}} \end{aligned}$$

An entirely automatic apparatus for the determination of low concentrations of sulphur dioxide in air was described by Thomas in 1929 (29). The automatic action was accomplished by using as absorbent a slightly acidulated distilled water solution containing about 0.006% hydrogen peroxide, the conductivity of the solution being determined.

The new method showed satisfactory agreement with the iodine method previously described. Both sulphur dioxide and sulphur trioxide in a gas mixture may be measured by making use of the iodine method to measure the sulphur dioxide and the hydrogen peroxide method to measure the total acidity. Generally the amount of sulphur trioxide is small compared to that of the sulphur dioxide and may be neglected.

In the investigations in the Trail and Windsor areas, continuous sulphur dioxide determinations were carried out by means of several Thomas automatic sulphur dioxide recorders (30). The reagent consists of a 0.015% hydrogen peroxide solution containing 50 cc. 0.01 N sulphuric acid in 20 litres of solution. This reagent has a resistance of approximately 10,000 ohms. The machine (Fig. 1) draws a measured volume of air through a definite volume of reagent for 20 min. and automatically discharges the aspirated solution at the end of

this period. This operation is accomplished by means of cams which open and close a series of valves in proper sequence. The 20-litre stock bottle placed at the top of the machine serves to hold the reagent which flows by gravity through cam-operated valves into calibrated pipettes of 100 cc. capacity. The contents of the pipettes are discharged into absorbers of about 350 cc. capacity. The air sample is drawn through the liquid after passing through a 5-mm. tube, the end of which is bent in the form of a loop perforated with a series of small holes on the underside to break up the air stream into small bubbles. The sulphur dioxide contained in the air is absorbed by the reagent and the conductivity of this reagent is automatically measured (Fig. 2). For this purpose platinum electrodes are sealed in the lower end of a glass tube, which extends about 1 cm. below the circular bubbler close to the bottom of the absorber, so that the gas bubbles do not come in contact with the platinum. Connections from the electrodes in each of the absorbers are made to a Leeds and Northrup recording Wheatstone bridge through a switch which changes the electric current from one absorber to the other simultaneously with the aspiration of the solution. A continuous record of the change in conductivity of each aspirated solution is given by the galvanometer which has a range of 125 to 40,000 ohms. Minor changes in conductivity caused by small temperature fluctuations are compensated for by the use of a rheostat and scale on the recorder, or by means of a compensating cell filled with the same volume of reagent as used in the absorbers. A continuous record of the air volumes is obtained by electrical contact through a relay with a Sargent gas meter.

While this type of recorder gives a continuous measurement of sulphur dioxide concentrations for each 20-minute interval of the day, so that the readings represent the average concentrations during this interval, peak concentrations occurring for shorter intervals may also be evaluated with considerable accuracy from the slopes of the curves drawn on the recorder charts. The recorder is calibrated by adding known amounts of sulphuric acid to the reagent and aspirating with measured volumes of pure air, since the sulphur dioxide absorbed by the reagent is entirely converted to sulphuric acid. From the data thus obtained a chart is prepared showing the change in conductivity in terms of sulphur dioxide concentrations in parts per million of air by volume per scale division on the recorder paper.

The automatic recorders are suitably housed in small well-built shelters with insulated walls. These shelters are heated throughout the greater part of the year and are equipped with automatic temperature control. The recorders are inspected daily or oftener, if necessary, and their performance is checked by competent observers.

Investigation of Sulphur Dioxide Conditions in the Trail-Northport Area TOPOGRAPHIC AND CLIMATIC CONDITIONS

The topographic and climatic conditions of the Trail-Northport area have a decided bearing on the frequency and duration of gas visitations from the Trail

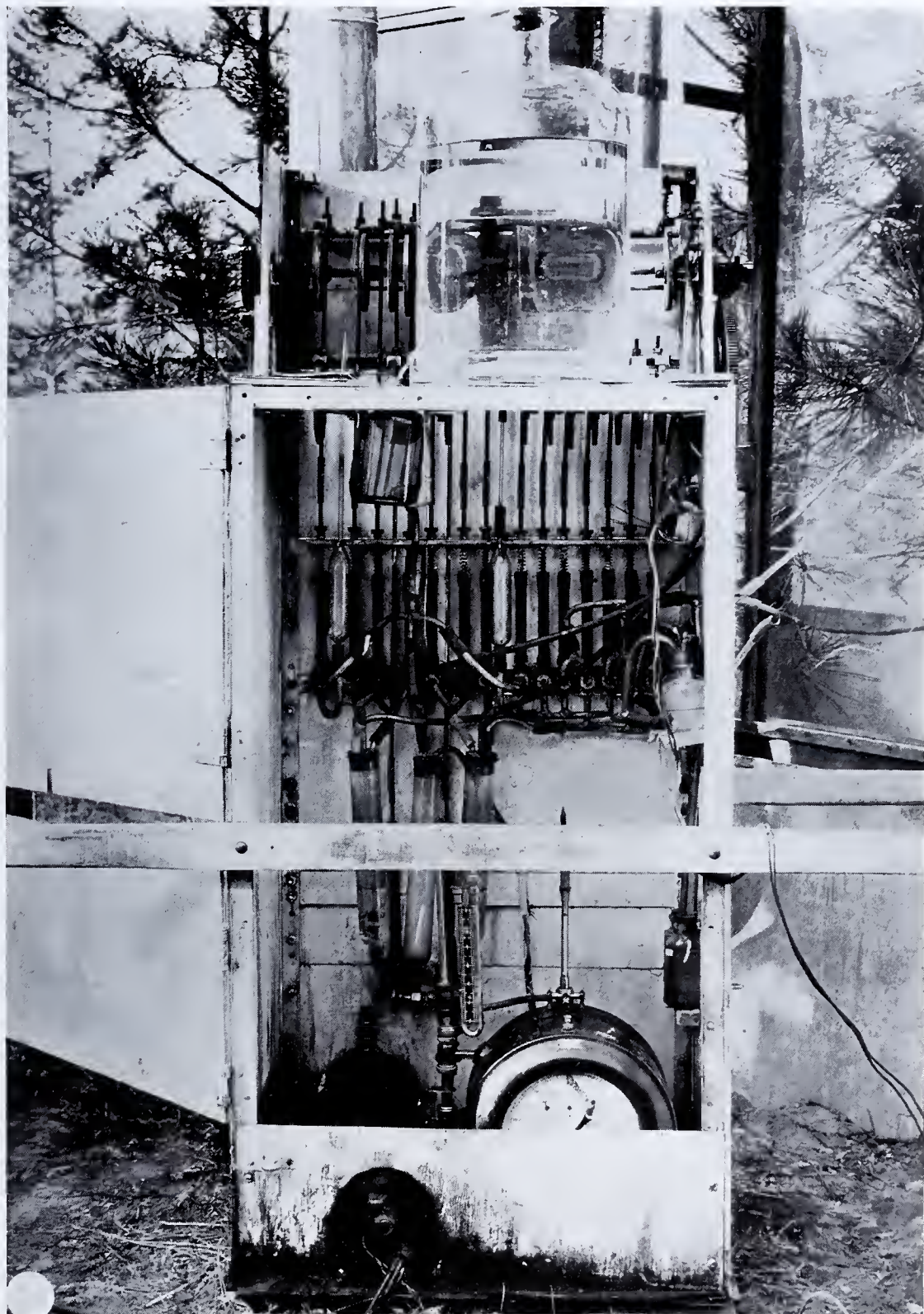


FIG. 1—*Thomas automatic sulphur dioxide sampling machine.*

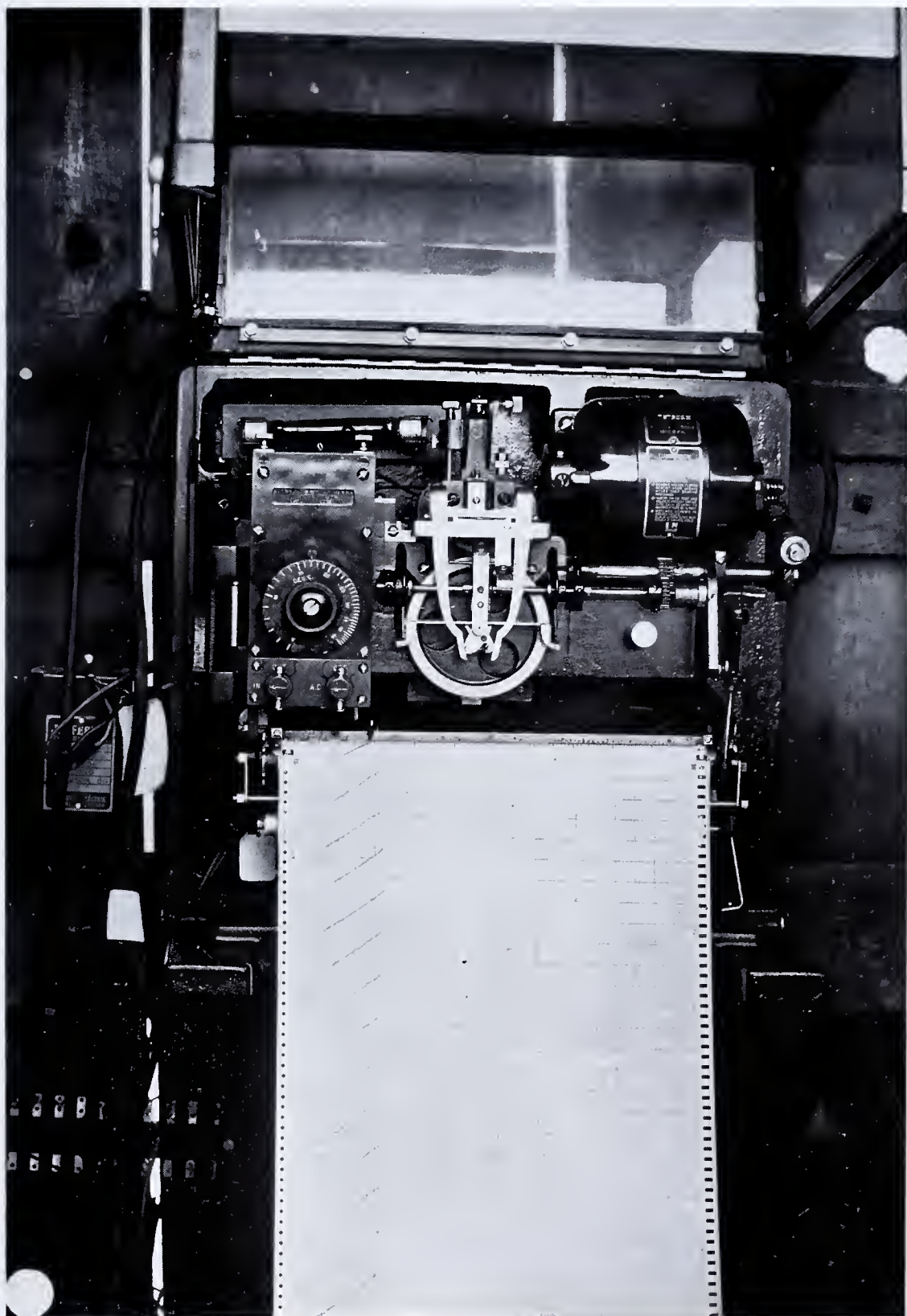
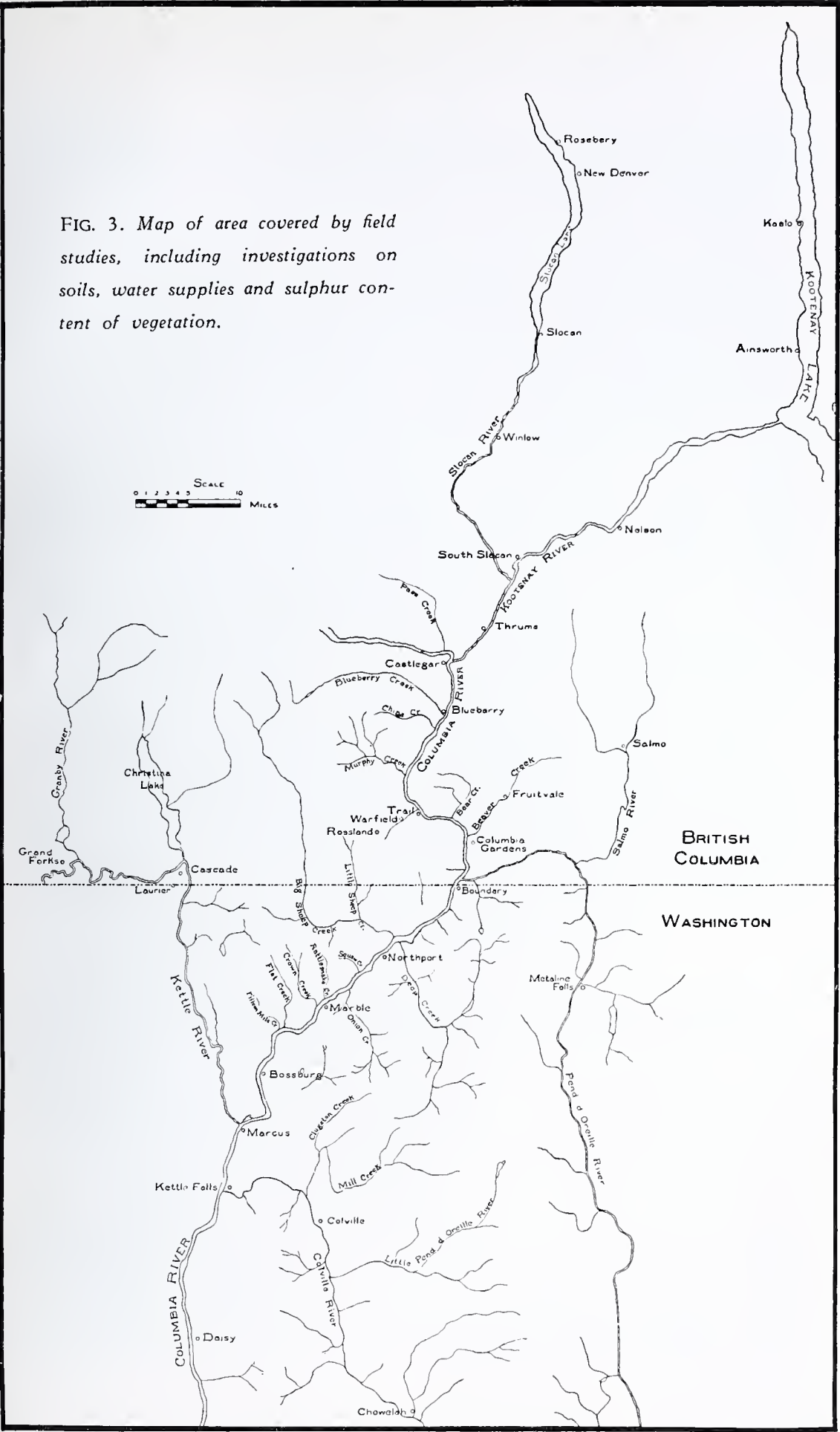


FIG. 2—Recording Wheatstone bridge galvanometer.

FIG. 3. Map of area covered by field studies, including investigations on soils, water supplies and sulphur content of vegetation.



smelter. The Columbia River drainage system in the broader area of southeastern British Columbia and northeastern Washington is shown in the map (Fig. 3), which also indicates the location of the principal towns and villages.

Topography

The towns of Trail and Northport are situated on the lowest river benches, in a relatively narrow valley or gorge cut out by the Columbia River. This valley is flanked on the east and west sides by ranges of high mountains which confine the smelter gases and prevent their spread either to the east or west, except in the case of tributary valleys formed by creeks. The main valley of the Columbia River, from Trail to Bossburg, consists of a succession of terraces rising about 700 ft. directly from the channel cut by the river. These terraces vary in width from less than a mile to about three miles, and are frequently broken by steep gravelly slopes. They are terminated by the mountain ranges which rise on both sides of the river to heights of about 3,000 to 4,500 ft. above sea level. The various creeks flowing into the Columbia River in the area between Trail and Bossburg are shown in the map. Of these the most important are Deep Creek and Sheep Creek. The tributary valleys formed by these creeks are generally much narrower than the main Columbia River valley and are terminated by high mountains. In the Sheep Creek valley near the International Boundary these mountains rise to a height of well over 5,000 ft.

The International Boundary is about 11 miles from Trail as measured along the Columbia valley. About half way between Trail and the boundary is Columbia Gardens, at which point a sulphur dioxide recorder has been stationed. The village of Marble is about 9 miles southwest of Northport, and about a mile beyond this point another sulphur dioxide recorder was stationed. Near Bossburg, about 27 miles from the boundary, the valley begins to broaden considerably and south of Marcus the character of the country changes, the river terraces becoming quite broad and more suitable for agriculture.

Winds

Though the path of the smoke stream is determined by the contour of the Columbia River valley, the frequency with which gas occurs in the Northport area is in a large measure dependent upon the character of the prevailing winds. The prevailing surface winds are either from the northeast or southwest, and since the Columbia River flows in this region from northeast to southwest it is readily seen that the smelter fumes emanating from the stacks at Trail tend to drift in the direction of the Columbia River valley.

According to the records of the U.S. Weather Bureau the winds are predominantly from the northeast during the period from midnight to 6 a.m. on nearly every day during the summer months. There is generally a change in wind direction to the south and southwest sometime during the remainder of the day. In the winter months there may be long periods during which the prevailing winds are persistently from the northeast without the daily change in

wind direction which is found to occur in the summer. This, coupled with the fact that, during the winter, low overhanging clouds, forming a low ceiling, prevent the rise of the smelter gases, serves to explain the greater duration of sulphur dioxide gas in the Northport area during the winter months.

The U. S. meteorological records at Northport indicate that for the period June 1, 1929, to May 31, 1930, exclusive of November, 1929, the prevailing wind was from the northeast for 245 days out of 335 during the hours from midnight to 6 a.m., and for 195 days out of 335 during the hours from noon to midnight. These meteorological conditions do not vary greatly from year to year. The following data show the variation of the prevailing winds during the summer months compared with the winter months. Thus, in June of 1930 there were four days out of the month during which the prevailing winds were entirely from the northeast. On 20 days of the month the winds were from the northeast for part of the day and southwest for the remainder. Similarly in July the days of northeast winds numbered nine, and those during which the prevailing winds were both northeast and southwest numbered 21. Similar figures were obtained for August and September. A change in wind direction from northeast to southwest would tend to place a limit to the duration of a particular gas visitation, and it is found that during the growing season the gas visitations from Trail may occur as often as the prevailing wind is from the northeast, but promptly disappear as soon as the wind changes to the southwest. This limits the duration of the fumigation generally to the morning period of the day.

The month of October usually marks a sharp change in wind conditions to those which prevail during the summer months. Thus, in October, 1930, prevailing northeast winds occurred on 17 days of the month, and on 11 of the remaining days the winds were from the northeast and southeast. Similar wind conditions occurred in October, 1934, whereas in 1935 during this month there were prevailing northeast winds on 24 days.

These northeast winds persist for extended periods during the winter months and affect the duration of the gas visitations from Trail. The month of February, 1935, was particularly notable in this respect, the prevailing winds being entirely from the northeast on 23 days and partly so on the remaining five days of the month.

The velocity of the surface winds is usually from two to five miles per hour, with an average of about four miles. These low velocities are maintained up to a height of about 600 to 800 metres above the surface. At higher elevations there is usually a marked increase in velocity and also a change in wind direction. Generally, westerly or southwesterly winds prevail at such times as the prevailing surface winds are from the northeast. The velocities reached by these upper winds at levels of 1,500 to 2,000 metres and higher may be 35 to 60 miles per hour. It is not unusual to find a gradual increase from five miles per hour at the surface to about 30 miles per hour at elevations above 800 metres from the surface.

Humidity

The relative humidity in this area is of importance in relation to susceptibility of plants during the growing season. It is chiefly during the periods of high humidity that symptoms of sulphur dioxide injury have been found in the past. During the early part of the growing season, particularly during early May, the humidity fluctuates between 90% at night and a low of 50% in the afternoon.

As the weather becomes warmer the humidity tends to drop and the range lies between 75 and 30%, or lower. During the periods of high temperatures, such as occur during July and August, the humidity drops to below 60% during most of the daylight hours, with a minimum of less than 30%. The months of highest humidity during the growing season are April, May, and September. Those of the lowest humidity are July and August; the latter part of May and parts of June are intermediate between these.

Precipitation and Temperature

The Trail-Northport region lies in a semi-arid belt, the average annual precipitation at Northport from 1923 to 1936 inclusive being about 17 in. The minimum was 9.60 in. in 1929 and the maximum 26.04 in. in 1927. During the period 1929 to 1934 for the months of March to August inclusive, the precipitation at Northport varied from a maximum of 9.49 in. in 1932 to a minimum of 5.08 in. in 1934. More detailed information in regard to precipitation will be found in Chapter VII dealing with tree growth.

With regard to temperature, the Northport meteorological records over the period 1929 to 1936 indicate that the lowest monthly mean temperature was 10°F. in January 1930, and the highest 71°F. in July 1931, and August 1929, 1930 and 1936. A maximum temperature of 110°F was recorded in July 1934. During the growing season period May-September, the mean monthly temperatures have fluctuated between 54 and 71°F. In the mid-summer months the days are hot and the nights cool, the daily temperature range usually being 30 to 50°.

SULPHUR DIOXIDE CONDITIONS

The investigation of the sulphur dioxide content of the atmosphere of the Northport area was undertaken in November, 1929, two automatic sulphur dioxide recorders and a portable apparatus being used. One recorder was placed in the main valley of the Columbia River near Marble, about 10 miles below Northport, Wash., and 30 miles south of Trail, B.C., and the other at a point up the Deep Creek valley, north of Northport, 18 miles south of Trail, and about five miles east of the Columbia River. The recorder at Deep Creek was moved on June 5, 1930, to a new location on the Stroh farm, about 15 miles south of Trail in the main valley of the Columbia River, and has been maintained there ever since. The Marble recorder was operated continuously from the date of its installation until about the end of June, 1934, when it was removed to a point on the west bank of the Columbia River, opposite Northport.

In April, 1937, a recorder was installed at Columbia Gardens, a point situated about six miles south of Trail, B.C., in the main valley of the Columbia River. A sulphur dioxide recorder was also operated for a period of about four and a half months, from July to November, 1930, near Marcus, Wash., approximately 50 miles south of Trail.

The early investigation covering the measurements taken by means of the two automatic recorders and a portable apparatus during the period November 1, 1929, to January 14, 1930, is summarized in Table II. The data include con-

TABLE II
SULPHUR DIOXIDE MEASUREMENTS
(November 1, 1929, to January 14, 1930)

Time covered by tests, hr.	1,637
Equivalent number of readings by portable apparatus	13,096
Average of all tests, p.p.m.	0.116
Zero readings (0.00 p.p.m.), % of total time	49.00
Readings 0.50-0.75 p.p.m., % of total time	4.01
Readings 0.75-1.00 p.p.m., % of total time	0.93
Readings above 1.00 p.p.m.	0.00

tinuous sulphur dioxide determinations at the fixed stations at Deep Creek and Marble, as well as readings taken at widely scattered points between the International Boundary (11 miles south of Trail) and Marcus. The maximum concentration found during this period was 0.96 p.p.m. at the Deep Creek recorder station.

Coincident with a period of continuous snow, rain and sleet in December, 1929, the automatic recorders registered sulphur dioxide, uninterruptedly, for about two weeks. The meteorological conditions were such as to prevent the normal diffusion of the smelter fumes. At the Deep Creek location in particular the gas conditions were unusual, the average concentration during a period of 188 hr. being 0.38 p.p.m., and the maximum, 0.96. That such conditions were unusual was indicated by the fact that, although the sulphur dioxide measurements were continued at this location until the end of May, 1930, the highest sulphur dioxide concentration found subsequently was 0.55 p.p.m. and the longest fumigation was of 55 hr. duration. Although there was a higher maximum concentration found during the period November 1, 1929, to January 14, 1930, at the Deep Creek location, than at Marble, the average at the former point was only 0.108 p.p.m., compared with 0.147 p.p.m. at Marble.

The data obtained from the automatic recorders have been of great value in showing the effect of the remedial measures undertaken by the smelter at Trail on atmospheric conditions in the area where considerable damage was found in the past. The sulphur emission from the stacks of the smelter has already been referred to (see Table I). There is no correlation between the daily sulphur emission at Trail and the gas visitations in the field since institution of smoke control measures. Quite often gas visitations occur precisely on

those days when the emission is low, but wind and weather conditions are favorable for the accumulation of gas. Since 1931, however, the control measures have effected a considerable decrease in the intensity of the gas visitations and have reduced the possibility of damage to vegetation, particularly at such times during the growing season when the susceptibility of plants is highest.

It will be seen from Table III, in which data are given for the period 1930 to 1937, that since 1930 there has been a marked reduction in the duration of readings of sulphur dioxide above 0.50 p.p.m. and also above 0.25 p.p.m. In

TABLE III
COMPARATIVE SULPHUR DIOXIDE DATA, 1930-1937

Year	Duration of sulphur dioxide		Concentrations above 0.25 p.p.m.		Concentrations above 0.50 p.p.m.	
	Hours	Percentage of total readings	Hours	Percentage of total readings	Hours	Percentage of total readings
<i>Stroh recorder—15 miles south of Trail, B.C.</i>						
1930 (July to Dec.)	1807.41	42.7	440.67	10.43	109.55	2.590
1931	2106.27	26.1	459.29	5.69	127.78	1.580
1932	1403.36	16.7	110.78	1.31	18.89	0.224
1933	1664.34	19.6	158.45	1.87	27.58	0.325
1934	3043.18	35.1	350.10	4.04	55.30	0.637
1935	3217.50	37.3	393.20	4.55	84.40	0.977
1936	2956.83	35.3	302.07	3.61	33.99	0.406
1937 (Jan. to Oct.)	2515.85	37.7	190.83	2.86	15.67	0.235
<i>Marble recorder—30 miles south of Trail, B.C.</i>						
1930	2376.64	27.3	420.28	4.86	38.64	0.448
1931	1496.03	18.5	205.29	2.53	33.32	0.412
1932	853.13	10.3	5.98	0.072	2.00	0.0241
1933	1019.01	12.2	24.98	0.300	1.99	0.0239
1934 (Jan. 1 to June 25)	1143.37	28.1	31.65	0.778	0.00	0.00

1930 readings of concentrations above 0.25 p.p.m. represented 10.43% of the total recorder readings at the Stroh recorder station, and 4.86% at the Marble recorder station. A decrease in the duration of these concentrations followed the adoption of the sulphur dioxide abatement measures instituted at the smelter in 1931, and a still further decrease was effected in later years. These results are shown graphically in Figs. 4 and 5, the time during which sulphur dioxide was present in the vicinity of the Stroh recorder for the half-year period, July to December, 1930, being doubled in order to compare it with the durations for the ensuing whole year periods. The trend shown by these curves obtained with the Stroh recorder is a pronounced drop from 1930 to 1932, followed by a slight rise from 1932 to 1933. From 1933 to 1935 there is a further increase in the periods during which the gas was present in concentrations greater than 0.50 and 0.25 p.p.m., but from 1935 up to the present time the trend is downward. This is of interest in view of the fact that the sulphur dioxide emission

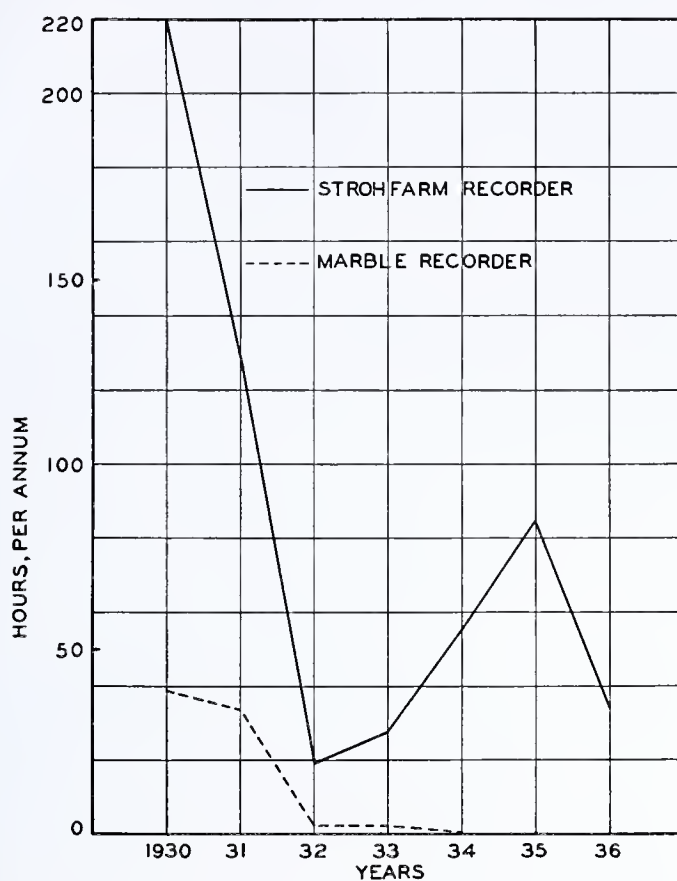


FIG. 4. Number of hours per annum during which the concentration of sulphur dioxide was above 0.50 p.p.m.

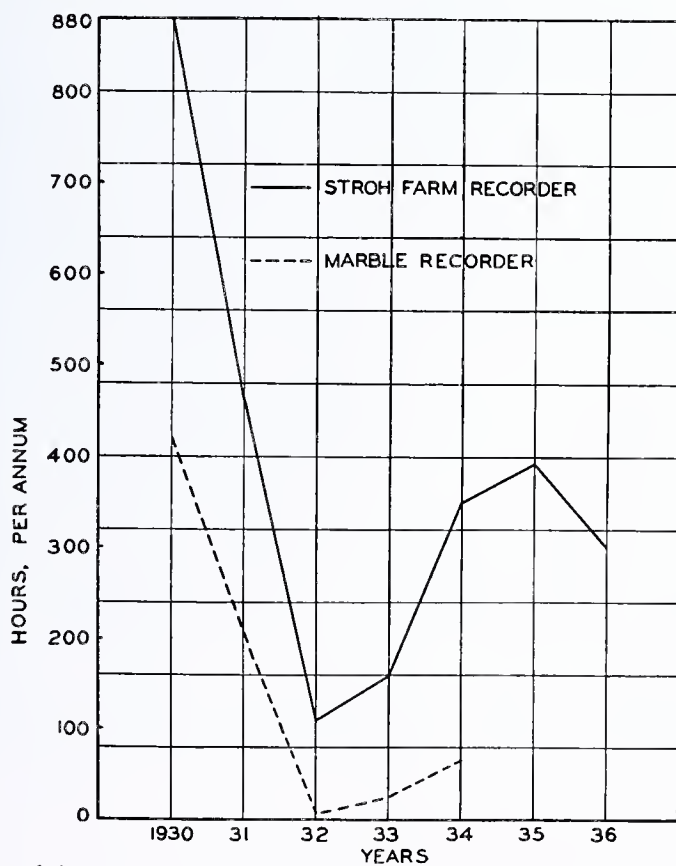


FIG. 5. Number of hours per annum during which the concentration of sulphur dioxide was above 0.25 p.p.m.

has been maintained at about the same rate since 1934, and indicates the effectiveness of more recent smoke control measures. The number of hours of these readings at the Marble recorder, 15 miles farther south, has been much less owing to the dilution of the gas with increasing distance from Trail.

The data in Table IV show the sulphur dioxide conditions for each of the summer periods, April 1 to September 30, during the years 1930 to 1937, inclusive, at the Stroh recorder station. The percentage of readings in excess of 0.10 p.p.m. has been markedly reduced since the years 1930 to 1931. From field observations and also experimental data it is known that the sulphur dioxide concentrations likely to injure vegetation after prolonged exposure are those greater than 0.20 p.p.m. and, in particular, those above 0.50 p.p.m. In 1930, concentrations in excess of 0.10 p.p.m. were present 16.9% of the time during

TABLE IV
COMPARATIVE SULPHUR DIOXIDE DATA FOR SUMMER PERIOD, APRIL 1
TO SEPTEMBER 30

Year	Duration of sulphur dioxide		Concentrations between 0.11 and 0.25 p.p.m.		Concentrations above 0.25 p.p.m.		Concentrations above 0.50 p.p.m.	
	Hours	Percentage of total readings	Hours	Percentage of total readings	Hours	Percentage of total readings	Hours	Percentage of total readings
<i>Columbia Gardens—6 miles south of Trail, B.C.</i>								
1937. May 1 to Sept. 30	1159.2	31.9	353.17	9.74	109.8	3.03	16.8	0.46
<i>Stroh recorder—15 miles south of Trail, B.C.</i>								
1930. June 10 to Sept. 30	924.2	33.5	255.7	9.30	210.6	7.60	40.5	1.47
1931	804.2	20.1	293.9	7.36	139.8	3.50	25.5	0.64
1932	679.8	16.1	71.3	1.69	8.5	0.22	1.9	0.045
1933	538.3	12.7	108.3	2.55	17.8	0.42	2.9	0.068
1934	912.5	20.9	145.2	3.33	32.5	0.75	3.6	0.083
1935	1236.5	28.4	244.8	5.64	35.8	0.82	2.6	0.060
1936	1024.0	25.1	276.8	6.78	47.2	1.16	4.0	0.098
1937	839.7	20.8	113.2	2.81	7.3	0.18	0.0	0.0
<i>Northport recorder—20 miles south of Trail, B.C.</i>								
1936	1027.7	23.6	227.2	5.21	50.8	1.17	3.8	0.087
1937	741.2	17.4	111.0	2.61	5.3	0.12	0.0	0.0
<i>Marble recorder—30 miles south of Trail, B.C.</i>								
1930	865.7	20.1	318.7	7.40	125.0	2.90	3.7	0.086
1931	420.1	10.7	109.6	2.80	9.7	0.25	0.0	0.0
1932	284.2	6.8	9.0	0.22	0.0	0.0	0.0	0.0
1933	254.8	6.2	9.3	0.23	0.0	0.0	0.0	0.0
1934. April 1 to June 25	260.7	13.0	7.3	0.36	0.33	0.016	0.0	0.0

the summer period, April 1 to September 30, which is equivalent to the growing season in this area. In 1931 this value decreased to 10.86%. During the growing seasons of 1932 to 1934, inclusive, the number of readings indicating these concentrations was less than 4.5% of the total number of tests. During the growing seasons of 1935 to 1936 there was an increase in these readings to 6.46% and 7.94% respectively. In the 1937 growing season, however, concentrations of this order were recorded for only 2.99% of the total time, the remainder of the readings being either zero or relatively innocuous concentrations less than 0.10 p.p.m. This value for 1937 is similar to the percentage of such readings recorded in the 1933 growing season. The average daily sulphur dioxide emission at Trail in 1933 was only about 67% of the emission during 1937. In 1933 the weather plan of operation in connection with the smoke control measures had not been instituted, and the results obtained during the 1937 growing season with this plan in full force illustrate the effectiveness of this mode of control.

The data in Table IV also show the dilution of smoke with increasing distance from Trail. A comparison of the results obtained during the 1937 summer

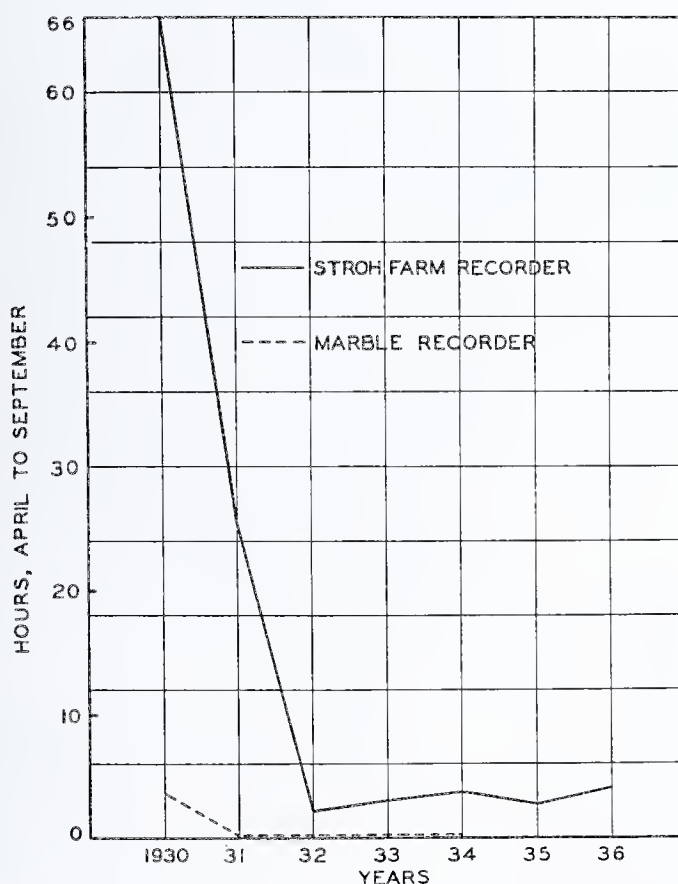


FIG. 6. Number of hours, April to September, during which the concentration of sulphur dioxide was above 0.50 p.p.m.

period at points 6, 15 and 20 miles south of Trail, shows that there is a decrease not only in the total time of occurrence of sulphur dioxide gas with increasing distance, but particularly in the recorded periods of the higher concentrations above 0.11 p.p.m. Similar examples of dilution are shown in comparative data for the Stroh recorder and Marble recorder. These results are also confirmed by those of the field investigations and the effect of sulphur dioxide on diameter increment of trees, the zones of highest damage or retardation in the past being those closest to the smelter.

The trend in the recorded hours of concentrations above 0.50 and above 0.25 p.p.m. is shown graphically in the curves, Figs. 6 and 7, for each of the growing

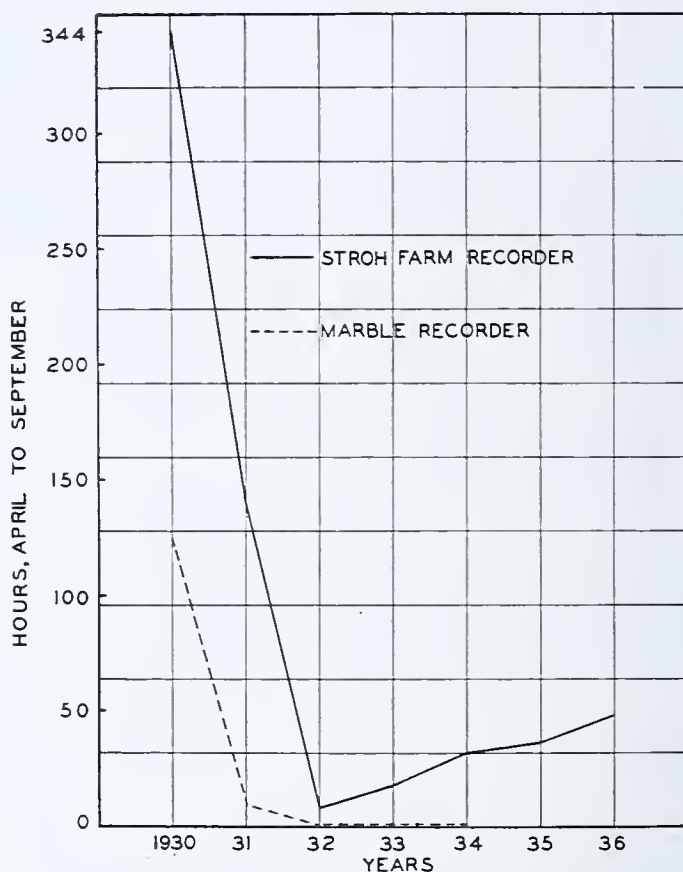


FIG. 7. Number of hours, April to September, during which the concentration of sulphur dioxide was above 0.25 p.p.m.

seasons from 1930 to 1936. The concentrations recorded at Marble are of a much lower order than those at the Stroh location, the maximum and average being substantially reduced over this distance of 15 miles. In fact, one of the reasons that prompted the removal of the Marble sulphur dioxide recorder to a new location on the west side of the Columbia River, opposite Northport, was that since January, 1932, the readings at Marble have been so low as to be of no consequence.

The Northport recorder readings do not show as great a dilution as would be expected in comparison with the Stroh recorder readings, five miles nearer Trail. The Northport recorder is situated on the west side of the Columbia River and the gas concentrations on this side are probably somewhat higher than those on the east side of the river for the same distance from the boundary owing to the topography of the Columbia River valley at this point. All the other recorder stations have been located on the east side of the river and readings are more comparable in this respect.

The data in Tables V and VI show the distribution of readings in each month of the growing seasons since 1930 at the Stroh recorder. The average of concentrations above 0.02 p.p.m. and also the average of all readings (including zero readings) have been reduced since 1930 and 1931. The average of all readings since 1932 has been no higher than 0.033 p.p.m. during the growing season, most of the averages being below 0.02 p.p.m. The highest maximum concentration found at the Stroh recorder station since 1935 was 0.76 p.p.m. in May, 1936. Only in the winter months since 1931 have sulphur dioxide conditions been comparable in some years to those prevailing in 1930. It has already been mentioned that the persistence of winds from the northeast, the low tempera-

TABLE V

COMPARATIVE SULPHUR DIOXIDE DATA FOR THE GROWING SEASONS, 1930 TO 1937, INCLUSIVE—STROH RECORDER, 15 MILES SOUTH OF TRAIL, B.C.

Year	April	May	June	July	August	September	Total per period
<i>Total hours of sulphur dioxide readings</i>							
1930	—	—	*103.98	242.98	284.64	290.99	922.59
1931	99.32	142.64	238.30	126.74	95.15	99.32	801.47
1932	113.48	80.92	116.19	74.50	49.17	112.80	679.80
1933	61.74	69.98	75.50	152.51	82.99	96.87	538.30
1934	216.10	188.90	114.00	119.30	139.30	134.80	912.50
1935	197.10	190.20	140.00	220.20	243.70	245.30	1236.70
1936	166.60	236.00	178.00	134.00	117.60	191.80	1024.00
1937	114.00	155.33	110.67	106.34	132.33	221.00	839.70
<i>Duration of sulphur dioxide above 0.25 p.p.m., hr.</i>							
1930	—	—	36.66	49.66	37.33	87.00	210.60
1931	16.33	27.33	51.82	18.00	7.33	19.00	139.80
1932	4.80	2.30	1.00	0.33	0.00	0.00	8.48
1933	2.40	2.00	0.66	8.90	0.00	3.80	17.76
1934	3.30	9.80	4.20	2.00	7.60	5.60	32.50
1935	8.60	5.30	7.60	0.00	6.10	8.20	35.80
1936	8.00	19.10	7.80	1.80	4.80	5.70	47.20
1937	2.00	0.33	1.00	0.00	0.00	4.00	7.33
<i>Average of all concentrations above 0.25 p.p.m.</i>							
1930	—	—	0.410	0.380	0.370	0.440	
1931	0.360	0.410	0.420	0.370	0.350	0.370	
1932	0.399	0.370	0.300	0.300	0.000	0.000	
1933	0.640	0.330	0.280	0.320	0.000	0.450	
1934	0.370	0.400	0.390	0.390	0.315	0.380	
1935	0.336	0.335	0.337	0.000	0.317	0.289	
1936	0.370	0.380	0.336	0.367	0.305	0.309	
1937	0.285	0.300	0.320	0.000	0.000	0.3415	

TABLE V continued

Year	April	May	June	July	August	September	Total per period
<i>Average of all concentrations above 0.02 p.p.m.</i>							
1930	—	—	0.230	0.170	0.120	0.210	
1931	0.170	0.190	0.210	0.170	0.140	0.180	
1932	0.104	0.084	0.078	0.067	0.049	0.079	
1933	0.081	0.100	0.085	0.120	0.070	0.110	
1934	0.095	0.115	0.087	0.069	0.101	0.096	
1935	0.101	0.104	0.102	0.085	0.106	0.106	
1936	0.115	0.129	0.130	0.089	0.092	0.113	
1937	0.060	0.072	0.082	0.0659	0.0714	0.0872	
<i>Average of all readings including zero readings, p.p.m.</i>							
1930	—	—	0.030	0.050	0.040	0.080	
1931	0.034	0.029	0.062	0.023	0.018	0.026	
1932	0.011	0.007	0.010	0.005	0.002	0.009	
1933	0.005	0.008	0.007	0.017	0.0069	0.0071	
1934	0.021	0.023	0.009	0.008	0.014	0.017	
1935	0.022	0.021	0.017	0.018	0.027	0.030	
1936	0.023	0.033	0.028	0.011	0.014	0.023	
1937	0.0195	0.0131	0.0102	0.0067	0.0093	0.0197	
<i>Maximum concentrations, p.p.m.</i>							
1930	—	—	0.92	0.90	1.05	2.11	
1931	0.77	1.25	0.87	0.94	0.55	0.74	
1932	0.68	0.60	0.36	0.30	0.16	0.20	
1933	1.30	0.44	0.30	0.53	0.20	0.70	
1934	0.55	1.00	0.65	0.58	0.48	0.60	
1935	0.64	0.61	0.48	0.25	0.60	0.64	
1936	0.68	0.76	0.60	0.38	0.42	0.42	
1937	0.32	0.30	0.34	0.16	0.25	0.48	
<i>Duration of maximum concentrations, minutes</i>							
1930	—	—	20	20	20	20	
1931	20	10	20	20	20	20	
1932	20	20	20	20	20	54	
1933	10	20	20	20	20	20	
1934	20	20	20	20	20	10	
1935	20	20	20	40	20	10	
1936	20	40	20	20	20	4	
1937	20	20	20	20	20	20	

*Sulphur dioxide measurements were begun on June 10, 1930

tures, absence of sunlight and the recurrence of cloudy weather and a low overhanging ceiling, tend to prevent diffusion and greatly offset the efforts of the smelter in regard to its weather plan of smoke control at this time of the year. A combination of these unfavorable factors accounts for the relatively long durations and higher concentrations found during some of the winter months. This is shown quite clearly in the chart, Fig. 8, where the monthly distribution of hours of sulphur dioxide above 0.25 p.p.m. from June, 1930, until June, 1937, is recorded graphically. Months during which unusual gas conditions prevailed since 1932 are February, 1934, January, February and November, 1935, January and February, 1936, and February and March, 1937. However, such gas conditions have not been harmful to vegetation in this area, since at this time of the year even the coniferous trees are either dormant, or

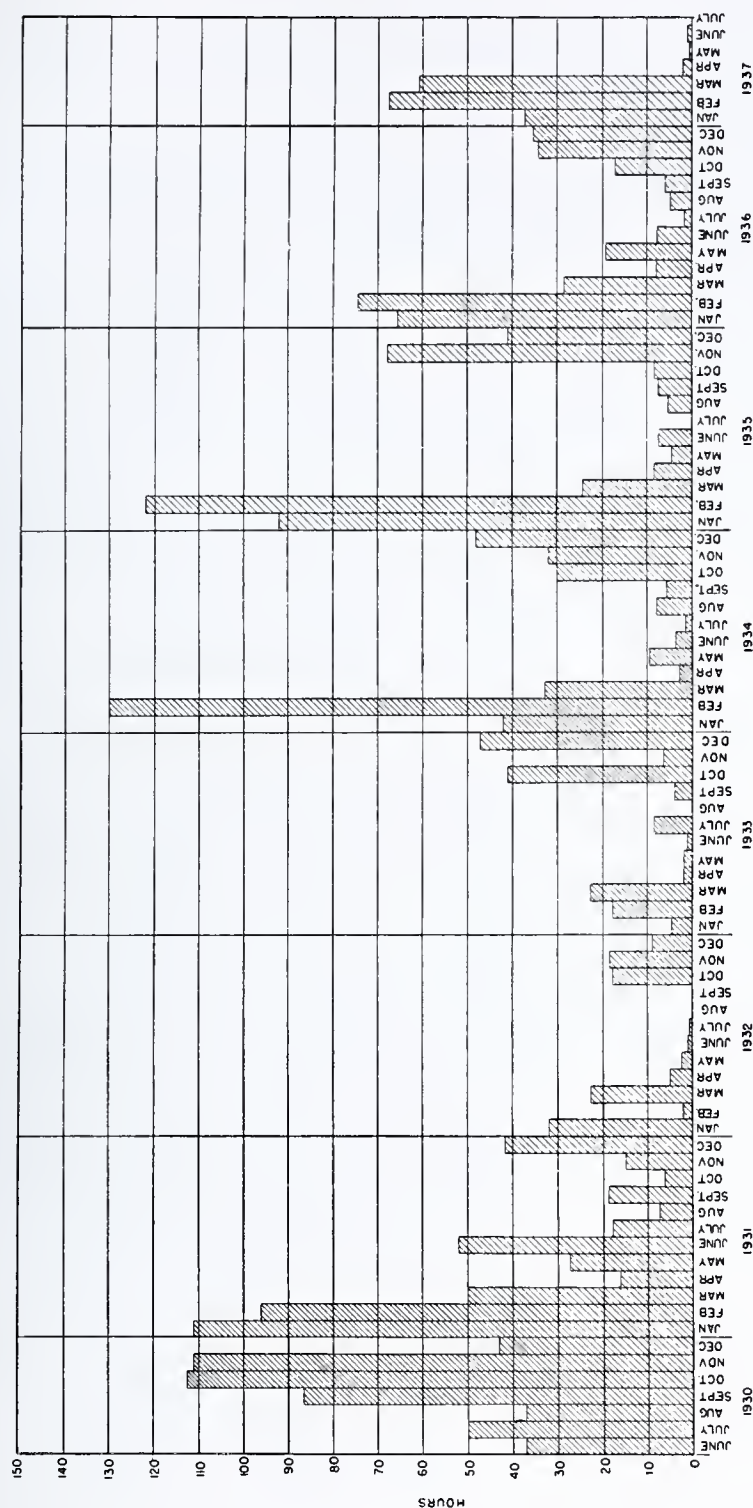


FIG. 8. Monthly distribution of hours during which the concentration of sulphur dioxide was above 0.25 p.p.m.—Stroh recorder.

at such a low level of activity that the absorption of sulphur dioxide by the leaves is negligible. Except for these months the chart shows a reduction in the recorded hours of these higher concentrations of gas in comparison with 1930 when no control measures were enforced in regard to sulphur dioxide emission.

TABLE VI

COMPARATIVE SULPHUR DIOXIDE DATA FOR THE GROWING SEASONS, 1930 TO 1937,
INCLUSIVE—STROH RECORDER, 15 MILES SOUTH OF TRAIL, B.C.

Year	April	May	June	July	August	September
<i>Zero readings recorded as percentage of total readings</i>						
1930	—	—	*82.9	65.5	60.8	59.2
1931	83.2	80.2	65.8	83.0	85.1	83.7
1932	83.8	88.7	83.3	89.0	92.9	84.3
1933	90.9	90.5	89.2	78.7	88.6	86.0
1934	69.7	74.1	84.0	83.7	81.2	81.6
1935	72.4	74.3	80.0	70.3	66.8	65.8
1936	75.1	67.6	74.6	81.9	78.7	72.3
1937	80.1	77.2	83.4	84.7	81.6	68.2
<i>Sulphur dioxide recorded as percentage of total readings</i>						
1930	—	—	17.1	34.5	39.2	40.8
1931	16.8	19.8	34.2	17.0	14.9	16.3
1932	16.2	11.3	16.7	11.0	7.1	15.7
1933	9.1	9.5	10.8	21.3	11.4	14.0
1934	30.3	25.9	16.0	16.3	18.8	18.4
1935	27.6	25.7	20.0	29.7	33.2	34.2
1936	24.9	32.4	25.4	18.1	21.3	27.7
1937	19.9	22.8	16.6	15.3	18.4	31.8
<i>Percentage of total readings below 0.11 p.p.m.</i>						
1930	—	—	6.56	17.76	21.75	18.60
1931	7.55	10.40	15.10	7.53	7.10	6.92
1932	12.90	9.56	13.67	10.20	7.07	13.04
1933	7.06	6.64	8.40	16.08	10.10	10.10
1934	25.04	18.60	14.37	15.35	14.67	13.29
1935	21.70	19.72	15.24	25.85	25.15	23.90
1936	15.72	22.60	12.80	14.73	17.50	19.50
1937	12.62	20.65	14.13	14.69	16.88	27.05
<i>Percentage of total readings between 0.11 and 0.25 p.p.m.</i>						
1930	—	—	4.53	9.68	12.32	10.00
1931	6.47	5.60	11.66	7.05	6.65	6.26
1932	2.61	1.42	2.889	0.751	0.03	2.66
1933	1.686	2.587	2.306	3.98	1.30	3.35
1934	4.797	5.96	1.04	0.676	3.10	4.345
1935	4.695	5.265	3.674	3.85	7.22	9.157
1936	7.985	7.175	1.49	3.13	2.93	7.38
1937	6.93	2.10	2.32	0.61	1.52	4.18
<i>Percentage of total readings above 0.25 p.p.m.</i>						
1930	—	—	6.01	7.06	5.13	12.20
1931	2.78	3.80	7.44	2.42	1.15	3.12
1932	0.69	0.32	0.141	0.049	0.00	0.00
1933	0.354	0.273	0.094	1.24	0.00	0.55
1934	0.463	1.34	0.59	0.274	1.03	0.765
1935	1.205	0.715	1.086	0.00	0.83	1.143
1936	1.195	2.625	1.112	0.243	0.869	0.823
1937	0.349	0.048	0.150	0.00	0.00	0.574

*Sulphur dioxide measurements were begun on June 10, 1930

The data in Tables VII and VIII indicate the sulphur dioxide conditions at three recorder stations situated at 6, 15 and 20 miles south of Trail in the main Columbia River valley. There is a considerable dilution of the gas from Columbia Gardens to Stroh, and a dilution of a smaller order from Stroh to Northport. The dilution in the region between Trail and a point 15 miles south is impressive both in regard to average and maximum concentrations.

In Table IX are listed all the fumigations of consequence in the vicinity of the Stroh recorder from June 10, when the recorder was put into operation, to September 30, 1930. The time of occurrence of each gas visitation, the duration, the average concentration, and the maximum are given. Similar data are shown in Table X for the entire growing season April to September 1936. A comparison of these two tables is of interest since smelter operations at Trail were maintained at about the same level during 1930 and 1936. The number and the intensity of such fumigations were much greater during the period June 10 to September 30, 1930, than for the whole growing season April to September 1936.

Details of the gas visitations of consequence at the Columbia Gardens recorder during the period May to July 1937 and at the Stroh recorder during the period April to July 1937 are shown in Tables XI and XII. The highest maximum concentration recorded for Columbia Gardens is 1.81 p.p.m., and the highest average 0.385 p.p.m. At the Stroh recorder the highest maximum shown is 0.32 p.p.m. and the highest average 0.161 p.p.m.

Detailed records of the data furnished by the automatic recorders were presented to the International Tribunal in the Trail Smelter arbitration case. Similar records were presented by scientists for the United States Government covering gas conditions at the International Boundary, Northport and Evans, the latter point situated about 45 miles south of Trail. From a careful study of these records the Tribunal came to the conclusion that a mechanism of gas distribution based on surface winds does not adequately explain the simultaneous occurrence of fumigations on numerous occasions at remote points down the valley. This phenomenon is especially noticeable during the growing season, April to October. It was the opinion of the Tribunal that the gases emitted from the stacks at Trail are carried into the upper air currents which have a much higher velocity than the surface winds and are thus spread in the direction of the prevailing wind in a fairly continuous stream (27). Under such conditions the fumigations which occur at various points along the Columbia valley are caused by the mixing of the surface air with this upper air current, the mixing process being governed by the temperature and velocity gradients of the region.

During the period May to September the most frequent fumigations occur in the early morning hours and are usually of short duration. Within a three- or four-hour period the gas concentration rises rapidly to a maximum, and then

TABLE VII
SULPHUR DIOXIDE OCCURRENCE AT THREE RECORDER STATIONS
Columbia Gardens — 6 miles south of Trail, B.C.
Stroh — 15 miles south of Trail, B.C.
Northport — 20 miles south of Trail, B.C.
(Figures given in per cent of total recorder measurements.)

Month 1937	Zero readings			Sulphur dioxide readings			Concentrations below 0.11 p.p.m.			Concentrations between 0.11 and 0.25 p.p.m.			Concentrations above 0.25 p.p.m.		
	Col. Gardens	Stroh	North- port	Col. Gardens	Stroh	North- port	Col. Gardens	Stroh	North- port	Col. Gardens	Stroh	North- port	Col. Gardens	Stroh	North- port
May	69.5	77.2	80.6	30.5	22.8	19.4	17.8	20.65	17.54	10.27	2.10	1.84	2.43	0.048	0.044
June	72.9	83.4	85.5	27.1	16.6	14.5	16.6	14.13	12.76	7.70	2.32	1.63	2.80	0.150	0.049
July	73.2	84.7	86.2	26.8	15.3	13.8	18.1	14.69	13.24	7.71	0.61	0.42	0.99	0.00	0.00
Aug.	74.6	81.6	86.5	25.4	18.4	13.5	13.6	16.88	12.17	8.87	1.52	1.27	2.93	0.00	0.047
Sept.	49.3	68.2	73.5	50.7	31.8	26.5	30.3	27.05	21.05	14.20	4.18	5.10	6.20	0.574	0.238
Oct.	36.9	45.3	49.2	63.1	54.7	50.8	28.4	34.60	37.90	17.25	13.22	11.53	17.45	2.52	1.36

TABLE VIII
AVERAGE AND MAXIMUM SULPHUR DIOXIDE CONCENTRATIONS AT THREE RECORDER STATIONS IN COLUMBIA RIVER VALLEY
Columbia Gardens — 6 miles south of Trail, B.C.
Stroh — 15 miles south of Trail, B.C.
Northport — 20 miles south of Trail, B.C.

Month 1937	Average of conc. above 0.25 p.p.m.			Average of conc. above 0.02 p.p.m.			Average of all measurements, p.p.m.			Maximum concentration, p.p.m.		
	Col. Gardens	Stroh	Northport	Col. Gardens	Stroh	Northport	Col. Gardens	Stroh	Northport	Col. Gardens	Stroh	Northport
May	0.413	0.300	0.280	0.146	0.072	0.076	0.035	0.0131	0.0114	0.90	0.30	0.28
June	0.429	0.320	0.280	0.148	0.082	0.075	0.033	0.0102	0.0081	1.81	0.34	0.28
July	0.349	0.00	0.00	0.119	0.066	0.064	0.027	0.0067	0.006	0.73	0.16	0.16
Aug.	0.336	0.00	0.260	0.162	0.071	0.074	0.030	0.0093	0.0074	0.68	0.25	0.26
Sept.	0.437	0.341	0.306	0.177	0.087	0.095	0.065	0.0197	0.0186	2.10	0.48	0.40
Oct.	0.418	0.324	0.351	0.218	0.107	0.103	0.116	0.0486	0.0424	1.73	0.55	0.76

TABLE IX
STROH RECORDER
June 10 to September 30, 1930

Date	Time	Duration of gas visitation, hr.	Average conc., p.p.m.	Maximum conc., p.p.m.
June 10	7.20 a.m. — 1.00 p.m.	5.6	0.332	0.83
15	5.20 a.m. — 12 noon	6.6	0.200	0.44
19	6.40 a.m. — 11.00 a.m.	4.3	0.171	0.36
20	5.00 a.m. — 6.00 p.m.	13.0	0.212	0.68
22	9.00 a.m. — 11.20 a.m.	2.3	0.184	0.51
23	1.00 a.m. — 11.00 a.m.	10.0	0.180	0.64
26	1.00 a.m. — 3.00 p.m.	14.0	0.390	0.81
26-27	5.00 p.m. — 10.20 a.m.	17.3	0.315	0.92
29	6.00 a.m. — 10.20 a.m.	4.3	0.273	0.49
30	6.00 a.m. — 12.20 p.m.	6.3	0.285	0.64
July 1	7.20 a.m. — 4.40 p.m.	9.3	0.339	0.69
2	7.40 a.m. — 12.20 p.m.	4.6	0.105	0.23
3	1.40 a.m. — 9.40 a.m.	8.0	0.200	0.51
3-4	9.00 p.m. — 10.40 a.m.	12.3	0.136	0.46
5	6.40 a.m. — 11.40 a.m.	5.0	0.275	0.49
7	7.40 a.m. — 11.00 a.m.	3.3	0.373	0.90
8	7.40 a.m. — 12.40 p.m.	5.0	0.371	0.79
9	6.20 a.m. — 2.00 p.m.	7.6	0.215	0.52
9-10	5.20 p.m. — 11.40 a.m.	18.3	0.195	0.52
11	6.40 a.m. — 4.20 p.m.	9.6	0.070	0.24
14	5.40 a.m. — 11.20 a.m.	5.6	0.105	0.29
18	6.40 a.m. — 10.40 a.m.	4.0	0.197	0.37
19-20	11.40 p.m. — 12 midnight	24.3	0.128	0.68
21	6.40 a.m. — 12 noon	5.3	0.226	0.53
22	7.20 a.m. — 12.20 p.m.	5.0	0.283	0.63
23	6.40 a.m. — 11.00 a.m.	4.3	0.255	0.57
23-24	7.20 p.m. — 11.00 a.m.	15.6	0.150	0.35
24-25	8.20 p.m. — 10.00 a.m.	13.6	0.178	0.52
27	6.20 a.m. — 11.40 a.m.	5.3	0.180	0.40
27-28	10.20 p.m. — 10.40 a.m.	12.3	0.152	0.38
28-29	Incomplete record			
29-30	11.00 p.m. — 12.20 p.m.	13.3	0.147	0.45
Aug. 3	6.40 a.m. — 11.40 a.m.	5.0	0.172	0.47
5	7.20 a.m. — 1.00 p.m.	5.6	0.165	0.34
6	7.00 a.m. — 12.00 noon	5.0	0.231	0.45
7	6.20 a.m. — 12.20 p.m.	6.0	0.188	0.49
8-9	1.00 a.m. — 2.00 p.m.	37.0	0.157	0.48
10	7.00 a.m. — 12.20 p.m.	5.3	0.188	0.59
10-11	8.00 p.m. — 12 noon	16.0	0.142	0.49
12	7.20 a.m. — 12.40 p.m.	5.3	0.199	0.45
13	8.00 a.m. — 2.40 p.m.	6.6	0.192	0.29
13	7.00 p.m. — 11.40 p.m.	4.6	0.146	0.45
14	8.00 a.m. — 1.00 p.m.	5.0	0.212	0.49
15	6.00 a.m. — 3.20 p.m.	9.3	0.231	0.53
16-17	9.20 p.m. — 1.40 a.m.	4.3	0.185	0.35
17	6.00 a.m. — 11.00 a.m.	5.0	0.193	0.45
18	7.40 a.m. — 11.40 a.m.	4.0	0.226	0.45
19-20	3.40 p.m. — 10.20 a.m.	18.6	0.124	0.35
21	7.00 a.m. — 11.20 a.m.	4.3	0.175	0.30
22	7.20 a.m. — 12.40 p.m.	5.3	0.144	0.26
23	8.40 a.m. — 12 noon	3.3	0.432	1.05
25	7.00 a.m. — 11.20 a.m.	4.3	0.229	0.44

TABLE IX continued

Date	Time	Duration of gas visitation, hr.	Average conc., p.p.m.	Maximum conc., p.p.m.
Aug. 26	7.00 a.m. — 11.00 a.m.	4.0	0.202	0.53
27	7.20 a.m. — 12.20 p.m.	5.0	0.173	0.43
27-28	8.00 p.m. — 12.20 p.m.	16.3	0.115	0.37
29	8.20 a.m. — 12.20 p.m.	4.0	0.270	0.77
Sept. 1	7.40 a.m. — 1.20 p.m.	5.6	0.255	0.94
1-2	7.40 p.m. — 1.40 p.m.	18.0	0.188	0.44
2-3	8.40 p.m. — 12.20 p.m.	15.6	0.160	0.55
3-4	6.40 p.m. — 2.40 a.m.	8.0	0.100	0.39
4	7.20 a.m. — 2.20 p.m.	7.0	0.212	0.37
4-5	5.20 p.m. — 3.20 p.m.	22.0	0.170	0.56
6-7	8.20 p.m. — 6.20 a.m.	10.0	0.299	0.76
7	11.00 a.m. — 5.00 p.m.	6.0	0.202	0.29
7-8	7.40 p.m. — 12.20 a.m.	16.6	0.275	0.58
9	8.20 a.m. — 11.40 a.m.	3.3	0.282	0.65
10	4.40 a.m. — 2.00 p.m.	9.3	0.132	0.29
16	7.20 a.m. — 12.20 p.m.	5.0	0.294	0.64
17	8.40 a.m. — 2.20 p.m.	5.6	0.172	0.56
19	8.00 a.m. — 2.00 p.m.	6.0	0.177	0.33
19-20	8.00 p.m. — 6.20 a.m.	10.3	0.097	0.39
20	8.20 a.m. — 2.00 p.m.	5.6	0.252	0.55
21-22	2.00 p.m. — 2.00 p.m.	24.0	0.437	2.11
24	8.20 a.m. — 5.20 p.m.	9.0	0.325	0.81
25-26	9.40 p.m. — 1.20 p.m.	15.6	0.390	0.84
26-27	5.20 p.m. — 4.40 a.m.	11.3	0.205	0.62
27	8.40 a.m. — 2.40 p.m.	6.0	0.215	0.58
29	8.40 a.m. — 4.00 p.m.	7.3	0.145	0.31
30	2.00 a.m. — 12 midnight	22.0	0.108	0.31

falls more gradually to a point below the limit of sensitivity of the recorder. The fumigations in such cases are probably influenced by the temperature effect of the rising sun on the atmosphere at the ground level. On the other hand, there are occasions when the surface winds determine the character and extent of the fumigations. At such times, the progress of the smoke down the valley may be readily followed by measurements with a portable apparatus. There is also a time lag in the appearance of the fumigation at the different recorder stations, the magnitude of which is governed by the velocity of the surface winds.

During the winter months the fumigations are usually of much longer duration. Here, if the gas visitations are due to the mixing of a gas-carrying upper air current with the surface atmosphere, the gas will persist in detectable amounts until diluted sufficiently by surface winds conveying air from outside the smoke region. When the surface winds subside completely and the temperature gradient is practically zero, *i.e.*, during cloudy, winter weather, gas visitations have persisted for uncommonly long periods. From observations on vegetation it would appear that upper air currents containing sulphur dioxide do not extend much beyond 2500 feet from the surface of the earth.

TABLE X
STROH RECORDER
April to September, 1936

Date	Time	Total hours gas	Av. conc. SO ₂ in p.p.m.	Max. conc. SO ₂ in p.p.m.
Apr. 10	5.20 p.m. — 12.00 midnight	6.6	0.137	0.36
" 11	7.00 a.m. — 2.00 p.m.	7.0	0.221	0.52
" 12	6.20 a.m. — 12.20 p.m.	6.0	0.151	0.36
" 15-16	5.00 p.m. — 8.00 a.m.	15.0	0.101	0.20
" 16-18	7.20 p.m. — 1.00 p.m. ¹	41.6	0.100	0.20
" 21-22	7.00 p.m. — 3.40 a.m.	8.6	0.095	0.22
" 22-23	3.40 a.m. — 11.20 a.m. ²	31.6	0.136	0.34
" 29	7.30 a.m. — 10.00 a.m.	2.5	0.392	0.68
" 30	6.40 a.m. — 11.40 a.m.	5.0	0.108	0.32
May 2-3	7.40 a.m. — 1.20 a.m.	17.7	0.183	0.57
" 3	5.20 a.m. — 12.20 p.m.	7.0	0.073	0.21
" 3-4	8.40 p.m. — 2.00 p.m.	17.3	0.076	0.24
" 8	7.00 a.m. — 10.00 a.m.	3.0	0.266	0.56
" 9	7.30 a.m. — 11.20 a.m.	3.8	0.415	0.76
" 10	3.20 a.m. — 5.40 p.m. ³	14.3	0.105	0.50
" 10-11	8.20 p.m. — 11.00 a.m.	14.7	0.162	0.32
" 12-14	9.00 p.m. — 11.00 a.m.	38.0	0.106	0.50
" 24	7.30 a.m. — 11.00 a.m.	3.5	0.170	0.24
" 28-29	10.40 p.m. — 9.20 a.m.	10.6	0.245	0.46
June 3	2.20 a.m. — 8.40 a.m.	6.3	0.195	0.30
" 7-8	8.00 p.m. — 10.20 a.m.	14.3	0.153	0.30
" 10	6.20 a.m. — 11.20 a.m.	5.0	0.190	0.36
" 10-11	7.40 p.m. — 1.40 p.m.	18.0	0.144	0.28
" 11-12	9.10 p.m. — 10.00 a.m.	12.8	0.154	0.31
" 12-13	6.20 p.m. — 1.00 p.m.	18.6	0.128	0.32
" 14	3.40 a.m. — 5.00 p.m.	13.3	0.128	0.60
" 14-15	7.40 p.m. — 12.40 p.m.	17.0	0.116	0.24

¹ Record missing for 2.3 hr. Northport figures used for broken period.

² Northport recorder—Stroh recorder shut down for repairs.

³ Record missing for 2.3 hr. Northport figures used for missing period.

TABLE X continued
STROH RECORDER
April to September, 1936

Date	Time	Total hours gas	Av. conc. SO ₂ in p.p.m.	Max. conc. SO ₂ in p.p.m.
July 3-4	6.40 p.m. — 12.40 a.m.	6.0	0.172	0.37
" 22	7.20 a.m. — 11.00 a.m.	3.6	0.181	0.38
" 28	7.40 a.m. — 11.00 a.m.	3.3	0.171	0.34
Aug. 10	8.00 a.m. — 10.20 a.m.	2.3	0.187	0.33
" 11	8.20 a.m. — 11.00 a.m.	2.6	0.178	0.37
" 18-19	3.20 p.m. — 10.40 a.m.	19.3	0.092	0.42
Sept. 2-3	8.00 a.m. — 10.40 a.m.	26.6	0.090	0.33
" 4	8.00 a.m. — 11.00 a.m.	3.0	0.179	0.26
" 9	8.20 a.m. — 11.00 a.m.	2.6	0.181	0.28
" 11-12	6.40 p.m. — 7.00 a.m.	12.3	0.186	0.34
" 16-17	8.20 a.m. — 2.20 a.m.	18.0	0.083	0.24
" 17	7.40 a.m. — 11.40 a.m.	4.0	0.126	0.38
" 17-18	9.40 p.m. — 11.00 a.m.	13.3	0.117	0.26
" 18-19	7.00 p.m. — 12.40 a.m.	5.6	0.128	0.35
" 23-24	7.20 p.m. — 1.00 a.m.	5.6	0.148	0.26
" 27-28	6.20 p.m. — 4.00 a.m.	9.6	0.082	0.27

Concentrations of Sulphur Dioxide in the Detroit-Windsor Area

During the period of March 12 to April 29, 1934, an investigation was carried out to determine the sulphur dioxide in the atmosphere in the Detroit-Windsor industrial area. Measurements were made by means of a portable apparatus at a number of different locations and also at two fixed stations by means of a Thomas automatic recorder. The fixed stations were situated at Riverside, a residential area about four miles northeast of Windsor, and at Sandwich, Ontario.

The measurements made with the portable apparatus indicated that sulphur dioxide was present on 18 days out of 30. The maximum and average concentrations are shown in Table XIII.

TABLE XI
COLUMBIA GARDENS RECORDER
May to July, 1937

Date		Time	Total hours gas	Av. conc. SO ₂ in p.p.m.	Max. conc. SO ₂ in p.p.m.
May	1-2	11.40 p.m. — 3.20 p.m.	15.7	0.166	0.60
"	2-3	10.40 p.m. — 1.20 p.m.	14.6	0.117	0.25
"	3-4	11.00 p.m. — 10.20 a.m.	11.3	0.121	0.24
"	6	7.10 a.m. — 11.00 a.m.	3.8	0.197	0.85
"	6-7	11.20 p.m. — 12.20 p.m.	13.0	0.116	0.24
"	9-10	5.20 a.m. — 6.40 a.m.	25.3	0.131	0.45
"	12	6.20 a.m. — 10.20 a.m.	4.0	0.145	0.30
"	13	7.40 a.m. — 11.40 a.m.	4.0	0.385	0.90
"	13-14	10.40 p.m. — 2.40 a.m.	4.0	0.338	0.52
"	15-16	11.20 p.m. — 6.20 p.m.	19.0	0.140	0.42
"	24	1.00 a.m. — 12.00 noon	11.0	0.131	0.33
"	24-25	11.40 p.m. — 11.20 a.m.	11.6	0.135	0.30
"	30	6.00 a.m. — 11.40 a.m.	5.6	0.177	0.33
"	31	6.20 a.m. — 12.40 p.m.	6.3	0.164	0.26
June	1	6.00 a.m. — 3.40 p.m.	9.6	0.120	0.28
"	2	6.50 a.m. — 10.40 a.m.	3.8	0.155	0.35
"	4	6.40 a.m. — 11.20 a.m.	4.6	0.314	1.45
"	5	7.20 a.m. — 9.40 a.m.	2.3	0.26	0.48
"	7	2.40 a.m. — 8.40 a.m.	6.0	0.116	0.54
"	10	5.40 a.m. — 1.00 p.m.	7.3	0.245	0.48
"	10	2.40 p.m. — 10.20 p.m.	7.6	0.105	0.25
"	13-14	2.20 a.m. — 12.20 p.m.	34.0	0.105	0.24
"	15	2.10 p.m. — 6.20 p.m.	4.2	0.232	0.54
"	16	3.00 a.m. — 1.30 p.m.	10.5	0.158	0.27
"	20	1.20 a.m. — 9.40 a.m.	8.3	0.092	0.40
"	25	7.10 a.m. — 10.40 a.m.	3.5	0.211	0.57
"	26	7.00 a.m. — 10.00 a.m.	3.0	0.345	0.56
"	28	7.40 a.m. — 12.00 noon	4.3	0.362	1.81
"	29	6.40 a.m. — 2.00 p.m.	7.3	0.151	0.26
July	4	7.40 a.m. — 11.40 a.m.	4.0	0.261	0.73
"	8	7.00 a.m. — 11.00 a.m.	4.0	0.181	0.40
"	10	7.40 a.m. — 10.40 a.m.	3.0	0.203	0.35
"	11-12	11.20 p.m. — 2.00 p.m.	14.3	0.110	0.31
"	12	4.10 p.m. — 5.40 p.m.	1.5	0.252	0.40
"	13	12.00 Mn. — 11.20 a.m.	11.3	0.083	0.31
"	18	7.00 a.m. — 12.00 noon	5.0	0.142	0.36
"	25-26	8.20 a.m. — 9.00 a.m.	24.6	0.109	0.32
"	30	2.10 p.m. — 2.40 a.m.	12.5	0.093	0.26

TABLE XII
STROH RECORDER
April to July, 1937

Date	Time	Total hours gas	Av. conc. SO ₂ in p.p.m.	Max. conc. SO ₂ in p.p.m.
Apr. 5-6	9.20 p.m. — 7.40 a.m.	10.3	0.105	0.25
" 12-13	9.00 a.m. — 9.20 a.m.	24.3	0.106	0.28
" 14	8.40 a.m. — 8.40 p.m.	12.0	0.115	0.24
" 24-26	3.00 p.m. — 1.20 p.m.	46.3	0.110	0.32
" 26-27	11.20 p.m. — 11.00 a.m.	11.6	0.063	0.21
May 6	7.00 a.m. — 9.40 a.m.	2.6	0.129	0.22
" 9	6.40 a.m. — 5.20 p.m.	10.6	0.074	0.30
" 30	6.40 a.m. — 11.00 a.m.	4.3	0.110	0.22
" 31	6.40 a.m. — 11.20 a.m.	4.6	0.141	0.18
June 1	6.20 a.m. — 11.00 a.m.	4.6	0.110	0.16
" 25	7.00 a.m. — 10.20 a.m.	3.3	0.161	0.28

TABLE XIII
SULPHUR DIOXIDE IN WINDSOR AREA AS DETERMINED BY PORTABLE APPARATUS
(IODINE METHOD)

1934	Average conc. sulphur dioxide, p.p.m.	Max. conc. sulphur dioxide, p.p.m.	Wind direction
March 13	0.069	0.11	South, dull.
20	0.396	1.93	Slight westerly drift, fog and smoke.
24	0.081	0.15	North, slow drift, some fog.
26	0.077	0.14	North, fog and snow.
28	0.170	0.27	Northwest, fog and smoke.
29	0.092	0.18	North.
30	0.047	0.12	Northeast, occasional westerly winds, cloudy.
31	0.083	0.17	West to northwest, rain.
April 2	0.069	0.15	Southwest and westerly, dull.
4	0.066	0.10	North and west winds, dull.
6	0.077	0.17	North wind, some fog.
7	0.087	0.14	Northwest, smoky, calm.
15	0.069	0.26	North, some rain.
17	0.082	0.15	Westerly, slight fog.
19	0.091	0.21	Southwest to westerly, clear.
20	0.057	0.10	Northwest to westerly, clear.
21	0.067	0.15	Northwest, dull, calm.
24	0.041	0.10	Southwest, occasional west winds.
25	0.039	0.13	Westerly, high velocity, clear.
27	0.072	0.14	Northwest, low velocity.

In view of the high concentrations found on March 20 it is interesting to record the conditions prevailing at that time. On the night of March 19 calm prevailed and smoke began to drift slowly over from the Detroit area to Windsor. This calm was maintained throughout the night and early morning of the 20th. Sulphur dioxide measurements were begun with the portable apparatus at 6.20 a.m., and appreciable concentrations were found to exist in the neighborhood of the international bridge at Windsor. The maximum concentration found here was 0.51 p.p.m. The fog and smoke were so dense that the outlines of the bridge could not be seen. At about 8.00 a.m. the portable outfit was taken to a new location farther south. The maximum concentration found here was 1.93 p.p.m. Sulphur dioxide was present in the air until about 10.00 a.m. when the fog was rapidly dispersed by east and south winds. The outline of the smoke or fog cloud could be plainly seen as it receded to the Detroit side of the Detroit River. The average of all sulphur dioxide determinations made during the morning with the portable apparatus was 0.396 p.p.m. The maximum concentration recorded on this day at the Riverside laboratory station, which is about 10 miles northeast of the point where the highest determinations were made with the portable apparatus, was 0.24 p.p.m. The fog was visibly more dense in the Windsor and Sandwich areas than in Riverside.

As a rule, higher readings were obtained by the portable apparatus than were found by the stationary automatic recorder owing to the mobility of the former which could be transported in the path of a given smoke stream. However, on two occasions the automatic recorder at Riverside registered extraordinarily high concentrations of sulphur dioxide for short intervals of time. The first occasion was on March 17 between 7.40 p.m. and 7.50 p.m. when 9.77 parts per million of sulphur dioxide were registered from 7.40 to 7.45 p.m., and 0.54 p.p.m. from 7.45 to 7.50 p.m. The rapid dilution of the sulphur dioxide from 9.77 to 0.54 to zero was due to the wind velocity of 19 to 23 miles per hour. On the second occasion, April 3, from 2.09 to 2.13 p.m., the recorder registered 4.67 parts per million. This dropped rapidly to 0.14 p.p.m. from 2.13 to 2.37 p.m., and then to zero. At Sandwich the highest reading obtained by the automatic recorder was 0.23 p.p.m., at about 2.00 a.m. on April 28.

Examination of the detailed records obtained by means of the portable apparatus of fumigations for which maximum and average concentrations only are reported in Table XIII, shows clearly that the Windsor industrial area did not contribute appreciably to the readings obtained, since the wind direction during these fumigations was almost invariably from the north, northwest, west, or, to a lesser extent, from the southwest, that is, from the direction of Detroit. With a change of wind direction to east, south, southeast or northeast, that is, from the general direction of Windsor toward Detroit, the sulphur dioxide concentrations dropped to low values, generally about 0.02 to 0.05 p.p.m., or disappeared entirely. The highest reading obtained with the portable apparatus when the wind direction was south, *i.e.*, from Windsor, was 0.11 p.p.m.

The automatic recorder readings at Sandwich, in the Windsor industrial area, obtained during the period April 17 to 28, indicate that concentrations only of the order of 0.02 to 0.04 were found when the wind direction was from the south, east, southeast, or northeast, *i.e.*, from the Windsor area.

However, change in wind direction was not always responsible for the dissipation of the sulphur dioxide. In some cases, with wind direction still from Detroit, an increase in wind velocity, or the appearance of bright, clear sunshine following dull foggy weather, with consequent improvement in diffusion conditions, brought an end to the fumigation.

With regard to the prevalence of sulphur dioxide in this area, the results indicate that gas was present in concentrations of 0.10 p.p.m. or over on 60% of the days during the period covered by the investigation. A total of 499 tests were made with the portable apparatus and 2,430 tests with the automatic recorder.

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CHAPTER III

SYMPTOMS OF INJURY ON FOREST AND CROP PLANTS

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Introduction

The problem of accurate diagnosis of symptoms of sulphur dioxide injury to vegetation is always of importance wherever this gas is known to be present in the atmosphere. If the concentrations of sulphur dioxide are of sufficient intensity and duration so that markings are severe, the area of damage may be defined without much difficulty. In border zones where sporadic fumigations of low intensity occur and consequently only a few very sensitive species of plants are lightly marked, the question of distinguishing between discolorations caused by sulphur dioxide and those due to insects, fungi and bacteria, drought, frost or sunscald, or other physiological disorders, becomes increasingly difficult. In such a situation the investigator may have to consider many factors before he can safely ascribe the markings found to the action of sulphur dioxide.

Knowledge of the concentrations and duration of sulphur dioxide is of great importance in estimating the amount of injury present. The use of automatic recorders, giving continuous records in certain locations over long periods of time, enables the field investigator to follow the effects of the fumigations with much greater assurance than would otherwise be possible. Either indicator plants or plots containing a susceptible species in which there is a special interest may be planted close to the recorders for more careful observation than would otherwise be possible in the area as a whole. With a knowledge of weather conditions and the amount of sulphur dioxide present, it is usually possible to determine the exact time when discolorations appear on these plants and to decide whether this gas is the causal agent. However, whether automatic recorders are available or not there will be large areas in which the vegetation present will be the only indicator for sulphur dioxide. It is therefore necessary to know the characteristic symptoms which sulphur dioxide produces on different plants in order to be able to separate these symptoms from those produced by other agencies. Chemical analysis of the leaves is a useful aid in diagnosis in those areas where the gas concentrations, although of prolonged duration, are of too low intensity to produce noticeable discolorations. They are most valuable when species of evergreens are used, the different years' needles being analyzed separately, and the accumulation in sulphur followed from year to year. In this way it is possible to get an outline of the zone of sulphur dioxide occurrence and thus avoid much useless searching for symptoms of injury in areas where the gas has not been present.

It is the purpose of this chapter to describe, illustrate, and compare the various markings and discolorations which have been found during the course of field studies in the vicinity of Trail, B.C. and experimental work conducted at Summerland, B.C.

The question of accurate diagnosis of sulphur dioxide injury has received considerable attention, especially by European investigators, and is a problem of special importance wherever smelting or other industrial enterprises discharge waste gas into the atmosphere and thus come into conflict with agrarian or forest interests. Before describing the various markings, it is of interest to review the work in this field carried out by other investigators.

Literature Review

One of the earliest detailed studies on the effect of sulphur dioxide on vegetation was made by Schroeder and Reuss in 1883 (15). By the use of colored plates they illustrate the type of acute markings which may be found on many species of conifers and deciduous trees. In the case of conifers, acute injuries are shown in a more or less characteristic damage to the tips of the needles. In spruce there is a very sharp differentiation between the red discolorations and the normal green part of the needles. Discolorations on the bark of young twigs, and some of the effects on the branches are described. The tips of the needles of larch did not show a clear-cut red discoloration, but were more or less dark reddish-brown, this color merging through yellow into green at the base of the needles. A sharp line of demarcation between the red of the tip and the green of the base was not as conspicuous as in the other conifers. In the broad-leaved trees, of which oak, red beech, birch, and ash were studied, smelter smoke damage was manifest as an irregular pattern of light and dark brown markings, usually present between the veins. Only occasionally were markings found on the margin of the leaves, and less often was there complete discoloration. The normal green color persisted longest on both sides of the main veins.

Schroeder and Reuss state that in young cereals and grasses the tips first become red, then yellow and lastly white. In the case of single leaves, tips were mostly affected, and in overhanging blades often the top was affected while the tip was still green. Bleaching of awns and glumes was found when smelter smoke damage was present during the flowering stage.

In various garden crops, such as turnips, potatoes, beans, and peas, also in forage crops such as alfalfa, the distribution and arrangement of markings was stated to be quite analogous to broad-leaved trees. Schroeder and Reuss are quite aware of the similarity between sulphur dioxide injury and various other injuries, such as those caused by frost, drought, sunscald, infertility of the soil, and other unfavorable environmental conditions. Attention must be given to the order of susceptibility of plants since, whenever species known to be resistant are injured more than susceptible species in the same vicinity, one must suspect agencies other than sulphur dioxide. Oak is listed as one of the most resistant species, followed by maple, ash, elm, poplar, white beech, red beech, and birch, in order of decreasing resistance. Of the field crops, potatoes and winter cereals are most resistant. The most susceptible are clover, forage plants, and grasses in the early stages of growth. It is interesting to note that even

in 1883 the question of "invisible injury" was under discussion. Schroeder and Reuss are of the opinion that smoke claims based on the theory of invisible injury to vegetation are inadmissible and contrary to the basic principles of exact science.

Sorauer and Ramann (16) published a series of papers on the question of invisible injury in 1899. The work was mainly concerned with chemical, botanical and microscopic investigations on spruce fumigated with 22 p.p.m. of sulphur dioxide for one hour daily and at longer intervals from June 1 to November 15. No visible symptoms of sulphur dioxide injury were noticed on the plants, although microscopic examination revealed injury to the chloroplasts. In view of the high concentrations used in this work, the absence of visible symptoms is difficult to understand.

The next detailed study of the sulphur dioxide problem appeared in 1903 in the form of a monograph by Haselhoff and Lindau (5). Most of the symptoms described by them are very similar to those given by Schroeder and Reuss. Acute injury is defined as that which through one or more fumigations in the same growing season brings about injury or death to vegetation. Chronic smoke injuries are manifest in a long-continued decrease in yearly growth. Haselhoff and Lindau regard birch, and red and white beech as the most susceptible of the broad-leaved trees. Of the cultivated fruit trees plum is the most susceptible and cherry somewhat more resistant. Mulberry is stated to be very resistant to sulphur dioxide.

In 1912 Hedgcock (7) published a paper on winter killing and smelter smoke injury in the forests of Montana. He claims to be able to distinguish between the two forms of injury and states that sulphur dioxide injury is reflected by a brighter color of the dead needles. In the case of lodgepole pine and Douglas fir, winter injury kills not only the leaves but often the terminal buds and twigs, and the whole tree may die in the following season. In acute sulphur dioxide injury the leaves die more gradually and terminal buds, especially of the top shoots, are the last to be killed. Death of trees due to sulphur dioxide takes place slowly by a more or less gradual defoliation often over a period of several years, whereas complete defoliation and killing by winter injury takes place in a short space of time. It is sometimes possible to differentiate between winter injury and sulphur dioxide injury as the order of susceptibility of different species to the two forms of injury is different.

One of the most detailed studies of smelter fumes injury was made by the Selby Smelter Commission in 1915 (9). The authors report detailed studies of the conditions around the Selby smelter and conducted fumigation studies with sulphur dioxide on barley. They describe two types of acute injury on barley; (1) a mottled type; (2) a concentrated or kill-back type of bleach, the latter occurring wherever barley was severely affected. They state that leaf maturity—that is the usual yellowing and death of the lower leaves on grain

and grasses and of the older leaves of trees—has been frequently pointed out as due to smoke, but it is necessary only to investigate this condition in other districts far removed from any possibility of smoke contamination to see that it is not an abnormal condition. They describe injury to leaves by sulphur dioxide in the form of intercostal spots and lines with the principal veins showing green amid the dead areas. The color of the dead parts is usually white, yellow brown, or red brown with intergradation, never black or pure red. It usually takes one to three days after injury for the color changes to be complete. Different species of plants vary greatly as to their susceptibility to sulphur dioxide injury and each has its peculiar markings and colorations, which in many cases are very similar to those produced by certain fungous diseases and insect injuries. The use of indicator plants for following the effect of sulphur dioxide injury in a smoke zone is recommended.

Stoklasa in 1923 (17) described three different types of injury; (1) acute, (2) chronic, (3) invisible. Acute injuries are those brought about by the action of abnormally high concentrations of sulphur dioxide, the characteristic symptom of which is the rapid disappearance of the chlorophyll. Chronic injury is a slower process involving the gradual breakdown of the chlorophyll. Photosynthesis then becomes abnormal, metabolism is lowered, and there is a retardation in growth of the plant. Invisible injury, according to Stocklasa, always is present wherever sulphur dioxide occurs in the atmosphere, even in the absence of acute or chronic injury. It is reflected in a lowering of the photosynthetic processes. Premature autumnal coloration of leaves is, in his opinion, in many instances, related to the injurious action of sulphur dioxide.

Neger (10) differentiates between acute and chronic injury, but says there is no sharp line of demarcation between the two forms. According to him the time of year is important in determining which form of injury will result; thus, in the winter small amounts of sulphur dioxide may barely produce a chronic effect, but when present during a period of high plant activity may lead to very pronounced, acute injury. He states the symptoms of chronic smoke injury are difficult to follow, and in the case of conifers are largely reflected in the shortening of the life of the needles, which in the case of spruce may be 2 to 3 years instead of 5 to 6, and in fir 4 to 5 years instead of the normal 10 to 12. According to Neger the susceptibility of the conifers to sulphur dioxide is as follows: fir, spruce, Scotch pine, white pine, Douglas fir, larch, black pine and yew in order of decreasing susceptibility. For broad-leaved species the order of susceptibility is red beech, oak, maple, linden, ash, mountain ash and birch.

Dorries (4) has recently developed a method which although not specific for sulphur dioxide serves to detect injuries caused by various acid gases. He believes that in the case of acute injury, the acid gas acts directly on the chlorophyll, changing it to phaeophytin through the splitting off of magnesium. The presence of phaeophytin in injured leaves was demonstrated by the use of a spectroscope. Phaeophytin is not present in the case of autumnal coloration or

drought, frost, and parasitic injuries. It does not arise also in leaves showing symptoms of chronic sulphur dioxide injury.

Bredemann and Radeloff (2) describe sulphur dioxide injury and methods of studying effects of this gas on vegetation in a publication which appeared in 1932. They state that the coloring of leaves is a visible change accompanying sulphur dioxide action and while the shape, form and color of the markings may be simulated closely by the discolorations which arise from frost, sunburn, etc., yet there are often certain characteristics which may be utilized to assist in the diagnosis. They point out that in studying smoke damage one should not depend on a single symptom but rather on a study of the situation as a whole. Most leaves of dicotyledonous plants have sharply defined markings, such as brown to red-brown, when these are caused by sulphur dioxide. The markings arise singly in the intercostal regions and unite, with increasing destruction, to form broad, colored areas. In the case of monocotyledons the leaf tips are colored first and there is a tendency for the markings to run in narrow strips between the parallel leaf veins. Since there is no specific method for detecting sulphur dioxide injury through botanical investigations these authors stress the importance of studying other factors, such as soil, air, etc., and making analyses of plant tissues in order to judge the sulphur dioxide effect.

Haselhoff, Bredemann and Haselhoff (6) stress the dependence of sulphur dioxide effect on external and internal factors such as intensity of fumigation, age of the plant, state of plant activity, and individual peculiarities related to the plant species. The most conspicuous changes are the discoloration of the leaf organs. Acute injury by sulphur dioxide causes needles and leaves to turn to a pale light green, to become wilted and curly. Later they often turn brown or brownish red, resembling frozen leaves. The stains penetrate the entire thickness of the leaf, but are stronger on the upper side, and are usually, but not always, surrounded by a darker first and a lighter second border. However, neither the color nor the shape of the markings on the leaves furnishes unmistakable proof that the injuries are due to sulphur dioxide. These authors discuss various types of markings on conifers, dicotyledonous, and monocotyledonous plants, the symptoms of which are similar to those already mentioned.

Wieler (18) recognizes acute and chronic symptoms of sulphur dioxide injury. Under acute injury he describes a "corrosion type" which does not appear to differ from the ordinary acute symptoms described by other investigators.

Acute injury is independent of functional disturbances, which are associated by Wieler with chronic injury. The first stage of acute injury cannot be followed macroscopically because there is no color change. The acid gas first stimulates the plasma so that the turgor rises and then drops slowly. This is followed by a discoloration of the chloroplasts and soon afterwards the cells die as a result of the direct action of the acid gas and not because of the derangement of assimilation. When the tissue dries out, the characteristic color changes resulting

from the oxidation of the tannins in light take place and give rise to the well known dark brown and red color tones. When no tannin is present the tissue turns white.

Hill and Thomas (8) give a description of the appearance and subsequent changes resulting from sulphur dioxide injury to alfalfa. The first symptom of injury is a noticeable stiffening of the leaves as though the cell had greatly increased in turgidity. The turgidity increases until certain areas in the leaf suddenly become flaccid and take on a watersoaked aspect. These flaccid areas bleach after a few hours of sunshine almost to an ivory color. Almost invariably the fully grown, highly functional leaves show the injury first and are more severely injured than the rest. Basal leaves were seldom marked and leaves that had not attained their growth, only rarely, whereas marks on stems were never observed. Another type of injury sometimes resulted after several days' fumigation. It differed from the acute markings in that the cells were not killed but there was a rather rapid disappearance of chlorophyll and the leaves become chlorotic.

Zimmerman and Crocker (19) published the result of some experimental studies with sulphur dioxide in 1934. They found that leaves of dicotyledonous plants become spotted and marked between the veins, the tissue about the veins being comparatively resistant. Injuries on monocotyledonous leaves varied from slightly mottled or bleached tips with low concentrations to completely bleached leaves when treated with higher concentrations. According to these writers the age factor is important in relation to the amount of leaf killing by sulphur dioxide. Middle-aged leaves were the most sensitive, followed by the older, while the youngest leaves were the most resistant. Leaf buds or developing leaves were very resistant. Among the species tested, buckwheat was the most sensitive and orchids the most resistant to injury by sulphur dioxide.

Native Vegetation of the Trail-Northport Area

The topography and climate of the Columbia River valley in which the smelter at Trail, B.C., is located have already been discussed in Chapter II. The area concerned with in the field studies of sulphur dioxide damage was that part of the Columbia River valley lying south of the smelter for a distance of about 50 miles from Trail, B.C., extending to the town of Marcus, Washington. The condition of the vegetation in the various tributary valleys of the Columbia River in this region for distances of from five to ten miles on either side of the Columbia River was also studied.

The forest in this region is essentially coniferous in character and all the conifers, with the exception of larch, are evergreen. For this reason the conifers reflect the sulphur dioxide conditions to a greater extent than the broad-leaved trees, since the needles are exposed to gas visitations year after year and the absorption of this gas becomes cumulative in effect. In the case of broad-leaved trees the leaves are shed in the fall and the following spring the

new leaves appear with their normal initial sulphur content, whereas in the conifers the needles of the previous year continue to absorb sulphur dioxide the following year and as long as they remain on the tree.

The most important coniferous species found in this region are:

Western yellow pine	— <i>Pinus ponderosa</i>
Douglas fir	— <i>Pseudotsuga taxifolia</i>
Western larch	— <i>Larix occidentalis</i>
Western white pine	— <i>Pinus monticola</i>
Western red cedar	— <i>Thuja plicata</i>
Grand fir	— <i>Abies grandis</i>
Engelmann spruce	— <i>Picea Engelmanni</i>
Lodgepole pine	— <i>Pinus contorta</i>
Hemlock	— <i>Tsuga heterophylla</i>

Of the species mentioned above those that occur in greatest number in the main valley of the Columbia River are yellow pine, lodgepole pine, Douglas fir and larch. The spruce, grand fir, white pine and cedar occur chiefly at higher elevations and are not very common.

Of the coniferous tree species only yellow pine, Douglas fir and larch are of commercial importance in the area under consideration. Some of the other species, although elsewhere of great economic importance, are represented in the main river valley only by scattered individual trees, whereas still others are confined to the upper mountain slopes and tributary valleys beyond the influence of smelter fumes. None of the broad-leaved trees in this area are commercially important, except, perhaps, the birch. The yellow pine is confined mainly to the benches and lower slopes adjacent to the Columbia River, although larch, Douglas fir, and lodgepole pine also occur here. Farther south along the river valley where the precipitation gradually decreases, yellow pine is the dominant species. Douglas fir is found occasionally but is of very poor quality. Larch occurs in localized areas where the soil is heavier and moisture conditions from sub-irrigation are more favorable than the average. In the side valleys and at upper levels in the main valley Douglas fir and larch are of better quality owing to the increased precipitation and heavier soil. The forest growth is more dense than on the lower benches and in addition to fir and larch includes scattered stands of cedar, white pine, grand fir, and alpine fir.

The slopes and benches were at one time much more heavily forested, but owing to lumbering operations and successive fires the major portion of the timber has been removed. Also in the region between Trail and about five miles south of the International Boundary a considerable number of trees have been killed by the effects of smelter fumes.

The broad-leaved trees occur in the main valley of the Columbia only to a limited extent. They are found here in certain localized areas where moisture

conditions from sub-irrigation are more favorable than usual. Along the creek bottoms up the tributary valleys, and at higher elevations where the coniferous forest has been logged off or burnt over, heavier stands of broad-leaved trees are found. The common species are as follows :

Paper birch	— <i>Betula papyrifera</i>
Mountain alder	— <i>Alnus tenuifolia</i>
Mountain maple	— <i>Acer glabrum</i>
Aspen	— <i>Populus tremuloides</i>
Black cottonwood	— <i>Populus trichocarpa</i>
Bitter cherry	— <i>Prunus emarginata</i>
Choke cherry	— <i>Prunus demissa</i>
Red hawthorn	— <i>Crataegus columbiana</i>
Elder	— <i>Sambucus glauca</i>
Mountain ash	— <i>Sorbus scopulina</i>
Willow	— <i>Salix spp.</i>

Interspersed with the broad-leaved trees and wherever the original coniferous stand has been thinned out there occurs a dense growth of shrubs. Because these shrubs are found up to within a few miles of the smelter and are plentiful all over this area, presenting a wide range of species which vary in their susceptibility to sulphur dioxide, they were specially useful as indicator plants.

The more important species which were kept under observation are as follows :

Ninebark	— <i>Opulaster malvaceus</i>
Ocean spray	— <i>Holodiscus ariaefolius</i>
Service berry	— <i>Amelanchier alnifolia</i>
Buck brush	— <i>Ceanothus velutinus</i>
Mountain laurel	— <i>Ceanothus sanguineus</i>
Hazel	— <i>Corylus rostrata</i>
Buffalo berry	— <i>Lepargyrea canadensis</i>
Mock orange	— <i>Philadelphus lewisii</i>
Snow berry	— <i>Symphoricarpos racemosus</i>
Thimbleberry	— <i>Bossekia parviflora</i>
Oregon grape	— <i>Odostemon aquifolium</i>
Dogwood	— <i>Cornus stolonifera</i>
Sumach	— <i>Rhus glabra</i>
Kinnikinnick	— <i>Arctostaphylos uva-ursi</i>

The ecology of the native vegetation on the mountain slopes and terraces beside the Columbia River near Trail has been entirely altered owing to the effects of many years' exposure to sulphur dioxide and repeated fires. In general, within five miles of the smelter, either north or south, the native grasses are conspicuous by their absence. Bracken fern and poison ivy are

two of the most common plants which still thrive. Close to the smelter, in gardens and parks, a wide variety of ornamental plants and a number of broad-leaved trees are grown quite successfully in spite of occasional severe injury from sulphur dioxide.

Conifers are practically absent in the main Columbia valley, except at high elevations, up to a point several miles south of the International Boundary at a distance of 12 to 15 miles from the smelter. Here and there a few more resistant yellow pine and larch have survived. Douglas fir appears to have been most severely affected, as normal trees of this species are not found growing as close to the smelter as any of the other conifers. Native aspen, willow, and maple still grow on favorable sites within a mile or two of the smelter. Fireweed is common in burnt-over areas, and though frequently marked by sulphur dioxide, is still abundant.

In the area under investigation it was found that the evergreen species, because they were exposed to visitations of sulphur dioxide gas year after year, suffered damage as evidenced by a retardation in growth, over a greater area than the field crops which are subject to gas fumigation only during one growing season.

I. Susceptibility of Forest and Crop Plants

Yellow Pine and Douglas Fir

In 1929 and 1930 definite sulphur dioxide markings were found on yellow pine in the valley of the Columbia River near the International Boundary. The acute symptoms of injury were present in a zone which did not extend beyond 15 miles south of the smelter. However, a study of diameter increment in yellow pine, made by means of borings, indicated a reduction in growth caused by sulphur dioxide in a zone which extended as far as 39 miles south of Trail. The great extension of the zone of injury was due to the effects of chronic injury as distinct from the acute symptoms noted in the more limited area near the boundary. During the years 1934 to 1936 no definite symptoms of acute injury were found on either yellow pine or Douglas fir in the smelter area. The effects of chronic injury were followed by diameter increment studies which are discussed elsewhere (see Chapter VII).

Western Larch

From both field observations at Northport and experimental studies at Summerland, it has been found that, of all tree species studied, western larch is the most susceptible to sulphur dioxide, and further that it is more susceptible than either alfalfa or ninebark.

Field Observations in 1930. The outstanding feature of sulphur dioxide injury in the Northport area in 1930, as far as the forest was concerned, was undoubtedly the severe injury to larch which occurred early in May. Warm

weather began towards the end of March and continued through April, the latter month being about as warm as May. The mean maximum temperature for March was 50.5° , for April 68.0° , and for May 68.5° F. The mean minimum temperatures for these three months were respectively 26.5° , 37.5° , and 41.5° . The mean temperatures were 38.5° , 53.0° , and 55.0° respectively. Precipitation for these months was 0.53, 1.62, and 1.58 in. respectively. Larch, which begins its growth much earlier than any other native conifer, had begun active growth early in April and by the end of April the foliage was almost fully developed. On May 2 a severe smoke visitation occurred. At a point in the main valley 14 miles south of the smelter the maximum concentration found by means of a portable sulphur dioxide apparatus was 1.50 p.p.m., and at Northport, 20 miles south, 1.39 p.p.m. Ten miles farther south at the Marble recorder the gas visitation continued for about 26 hr. with a maximum concentration of 0.48 p.p.m. At the Deep Creek recorder, situated 18 miles south of Trail and three miles east of the Columbia River, up a tributary valley, the fumigation lasted about 12 hr. with a maximum concentration of 0.52 p.p.m.

The larch began to show the effects of this gas visitation from three to four days later when the leaves of many trees turned from green to a straw color and gave off a marked pungent odor. About ten days later, or about May 15, the injured foliage assumed a reddish-brown color (testaceous to ferruginous (13)), which changed but little through the summer but became darker during the fall. By May 23 severely injured trees had begun to put out new foliage, but on May 27 and 28 there was another fairly severe fumigation which damaged this new foliage. This occurred again during June. None of the larch trees which were at all seriously injured regained a normal set of leaves later in the same season. Observations made upon injured larch did not tend to support the view that leaves which had been injured by sulphur dioxide drop off shortly after the injury had taken place. In fact the leaves remained on the trees, and even seven months after the damage was done most of the foliage which was severely injured in May still persisted on the trees.

The extreme limit of the area in which larch was found to be affected by sulphur dioxide in 1930 was about 33 miles south of Trail in the main valley of the Columbia River. The injured trees were confined to elevations below 2,500 ft., *i.e.*, 1,175 ft. above the Columbia River. In the tributary valleys of Deep Creek, Sheep Creek, and Cedar Creek there were considerable extensions of the zones of injury for distances of three to five miles up these valleys.

In order to obtain some data in regard to the percentage of larch which had been damaged by sulphur dioxide, counts of trees at four different locations were made with the following results:

TABLE I

Location (south of the smelter)	Per cent of larch injured		
	Severely	Slightly	Uninjured
1—11 miles, in Sec. 2-40-41	73	7	20
2—15 miles, near Stroh farm, N.W. $\frac{1}{4}$ Sec. 25-40-40	50	13	37
3—18 miles, near the mouth of Deep Creek, centre Sec. 34-40-40	34	18	48
4—3 miles southeast of the Columbia River in a tributary valley and about 13 miles from the smelter in a direct line, N.E. $\frac{1}{4}$ Sec. 14-40-41	15	10	75

At each location, except No. 2, where there were not sufficient trees, 100 larch were counted and classified just as they occurred, without any selection. At location No. 2, thirty trees were counted. The basis of calculation was as follows: severely injured—foliage entirely discolored, none of the first set of leaves showing any green; slightly injured—injury not complete as in the first class, either part of the foliage entirely discolored and the remainder green, or else a tip injury of the leaves over the whole tree; uninjured—leaves green and showing no effect from sulphur dioxide. These figures are significant in that they show the damage to have been very severe nearest the smelter and decreasingly so as the distance increased. They also show that out of the Columbia valley the injury was much lighter.

In regard to this species there is no doubt that in the early part of the growing season—about the time that the foliage has completed its growth—the leaves are extremely sensitive to sulphur dioxide. If this peak of susceptibility is passed without injury, the foliage is much more resistant and is marked only occasionally. For instance on September 21 of 1930 there was a much more severe fumigation than that of May 2, but as far as one could tell no injury to larch resulted from it. At the Stroh recorder the visitation lasted for about 22 hr. with a maximum concentration of 2.11 p.p.m., while at Marble it continued for about 19 hr. with a peak of 0.93 p.p.m.

In spite of the fact that larch is so readily injured at certain times there is no doubt but that it is the conifer most resistant to killing by sulphur dioxide. On all sides of Trail it is the conifer which is found nearest to the smelter, and between 10 and 20 miles south of Trail, in the immediate river valley, there are more larch than any other species. This resistance to killing is probably to be accounted for by its short period of extreme susceptibility and also by the fact that it is a deciduous species, *i.e.*, its leaves are shed each autumn, and so are not subject to the cumulative effects of fumigations year after year to the same extent as the evergreen conifers.

Field Observations in 1931. Early in May, 1931, there was scarcely any sign of sulphur dioxide injury on sensitive plants in the main Columbia River valley. The larch, even in the area closest to the smelter, *i.e.*, from 10 miles south as far as Northport, was quite green. Although sulphur dioxide visitations were quite numerous in April and early May, the first signs of injury to larch were noted after a fumigation which occurred during the period of May 22 to 24. This lasted for about 31 hr. at the Stroh recorder station (15 miles south of Trail), the maximum 20-min. reading being as high as 1.25 p.p.m., and the average of all the positive readings, 0.21 p.p.m. Markings were found on larch following this fumigation in the immediate vicinity of this recorder and in the intervening zone towards the smelter. Farther down the main valley the larch was uninjured, although at the Marble recorder station (30 miles south of Trail) the gas visitation was recorded for a period of about 20 hr., but the maximum concentration was only 0.24 p.p.m. and the average less than 0.10 p.p.m.

During the last four days in May and the first week in June there occurred a further series of gas visitations, the total of which induced further slight markings on the sensitive plants between Northport and Trail. Further markings appeared on larch trees, especially in the area a short distance up the Sheep Creek valley. Although the fumigations which occurred almost daily during this period were of only four to six hours' duration, the maximum concentrations were rather high, being, in general, between 0.50 and 1.00 p.p.m. at the Stroh recorder station.

The next fumigation which caused considerable injury on larch was that which occurred between June 14 and 16. The gas visitation, at the Stroh recorder, lasted 56 hr., with 47.6 hr. of significant readings with a maximum concentration of 0.67 p.p.m. and an average of 0.254 p.p.m. At the Marble recorder the gas visitation lasted for 46 hr., with a maximum concentration of 0.41 p.p.m. and an average of 0.153 p.p.m. Larch was again injured in the area between Trail and Northport. There were no positive indications of acute markings on larch below Northport, and it is interesting to observe that the gas visitation at Marble, although quite prolonged, was yet not sufficient to cause markings on either larch, fruit trees, or shrubs. During the remainder of this growing season no further markings appeared on larch despite the frequent occurrence of sulphur dioxide.

Field Observations in 1934 and 1935. On May 4, 1934, a fumigation occurred which injured larch over a considerable area though neither yellow pine nor Douglas fir was marked. The injury to larch, however, was not comparable, either in extent or intensity, to that which resulted from the severe fumigation of May 2, 1930. March and April of this year had been very warm months with favorable precipitation, so that by the end of the first week of April the buds of larch had begun to expand. By the beginning of the last week of that month the leaves were fully developed, so that when the fumigation occurred

about 10 days later the trees were just at the peak of susceptibility to sulphur dioxide.

At the time of this fumigation in May at the Stroh automatic recorder, 15 miles south of the smelter, sulphur dioxide was present over a period of 20 hr. with a maximum 20-min. reading of 1.00 p.p.m. under weather conditions which were favorable for injury, the range of relative humidity during this period being 70 to 92%. At Marble, 15 miles farther south, however, the maximum sulphur dioxide concentration was only 0.28 p.p.m., and there was no injury to larch. The approximate limits of the area in which larch was injured this year was about one-fourth of that of 1930. In 1930 the area extended down the river valley 13 miles farther than in 1934 and there were very considerable extensions into the tributary valleys of Deep Creek, Sheep Creek, and Cedar Creek. In 1934 there was practically no injury in either Deep Creek or Sheep Creek valleys and none at all in the Cedar Creek valley. Further, the injury this year did not extend as far up the mountain slopes as in 1930, and in the main Columbia valley it extended to Northport only, a distance of 20 miles south of the smelter.

There was an even more striking difference in the degree of injury. In 1930, counts of trees at the Stroh ranch and at the mouth of Deep Creek showed that approximately 63 and 52% respectively of the larch at these two points was marked. In 1934 at the same places there were only 3 and 2% respectively of the larch injured, and none of these died subsequently.

There were no acute symptoms of sulphur dioxide injury found on larch in this area during the growing season of 1935. The spring months were abnormally cool and dry, and growth was from two to three weeks later than usual. Furthermore, although the total duration of sulphur dioxide visitations in this area was similar for the months of May and June to that for the corresponding period of 1934, the fumigations in 1935 were in general of lower intensity. The coincidence of the above factors is sufficient to account for the absence of injury to larch.

Field Observations in 1936. In 1936, with early warm spring weather, growth was more advanced than in 1935, and early in May the foliage of larch was fully expanded. Sulphur dioxide injury to larch occurred over a large area following a series of gas visitations in the latter part of April and the first few days in May. The most important of these took place on May 2, a day of high humidity, during which sulphur dioxide was present continuously at the Stroh recorder, and for a period of six hours the readings were above 0.25 p.p.m. with a maximum of 0.57 p.p.m. The foliage on May 11 was still a dull straw color which is the characteristic appearance of injured larch foliage for a short time after a damaging fumigation. In some trees the foliage was entirely discolored, in others there was partial injury, but many trees showed no effect whatever. About 10 days later the color of the injured leaves changed to a reddish-brown

which gradually became duller in hue as the season advanced. The injured foliage persisted on the trees throughout the summer and, in fact, was still present in the spring of 1937. On the severely injured trees many twigs and tips of branches were killed.

The area in which larch was injured extended almost to Bossburg, a distance of 38 miles from Trail with considerable lateral extensions in Sheep Creek, Deep Creek, and Nigger Creek valleys, and, to a less extent, into Cedar Creek valley. In general, injury was confined to the lower elevations, at no place having been observed, even near the smelter, as high as 2,500 ft. above sea level.

Only a few larch trees were killed outright as a result of this early injury. An estimate of injured larch made at various points during the summer of 1936 is given in Table II.

TABLE II

Distance (south of smelter)	Larch injured in 1936		
	Trees injured	Trees uninjured	Percentage injured
12 miles, (west side of Columbia River)	16	24	40
15 miles, (west side of Columbia River)	21	25	46
Northport, 20 miles, (west side of Columbia River)	90	96	48
26 miles, (east side of Columbia River)	100	48	68
31 miles, (west side of Columbia River)	50	52	49
	277	245	53

These figures, which are to be regarded as only an approximation, indicate that 53% of the larch stand in the immediate valley of the Columbia River for a distance of 31 miles, was injured by sulphur dioxide. Out of 372 of the same trees which were examined again in the spring of 1937 only one was found dead, but 236 still showed residual injury. Although the percentage of injured larch in 1930 was about the same as in 1936, the rate of mortality was very much greater, 34% of the affected trees having died by 1931. This difference in mortality was mainly due to the fact that in 1930 the larch was injured several times during the growing season.

Susceptibility of Larch in Experimental Fumigations. Experiments on the effect of various sulphur dioxide concentrations on larch grown in plots at the Dominion Experimental Station, Summerland, B.C. also show the susceptible character of this species (Chapter X). Thus symptoms of injury appeared in each case after eight-hour fumigations at the end of May, with average concentrations of 0.30 and 0.43 p.p.m., the humidity being maintained at 67 and 75%, respectively. With lower average concentrations, the minimum being

0.10 and the maximum 0.60 p.p.m., the first symptoms of injury appeared after about 82 hr. of practically continuous treatment. A maximum concentration of 0.60 p.p.m. was present for one hour, and the average for the whole period was 0.184 p.p.m.

The various symptoms of sulphur dioxide injury to larch under experimental conditions are described in Chapter X. In these fumigation experiments the leaves on the current year's wood were much more susceptible than those on wood of previous years. In the field, however, this difference was not nearly so marked, because injury occurred generally in early May before the new wood was formed. Also at Summerland the affected larch leaves were shed quite soon after injury because of the absence of fascicles, the leaves on the new wood being attached singly to the shoots, whereas those on older wood occur in fascicles.

Broad-leaved Trees and Shrubs

Field Observations from 1930 to 1936. While the broad-leaved trees and shrubs are not of commercial importance in this area they, nevertheless, form a considerable part of the native vegetation, serve to protect the soil from erosion, and conserve the water supply. Because of the widespread occurrence of many of these species in the Columbia valley and its tributaries, observations on the extent of acute markings on such trees and shrubs were found useful in delimiting the region where there existed substantial hazard from sulphur dioxide. The main part of the field work was devoted to conifers and crop plants, but some observations were always made on the most sensitive broad-leaved trees and shrubs as an incidental part of the work.

In general, injury to shrubs and broad-leaved trees in the main river valley was much more severe in 1930 and 1931 than in any of the years 1934 to 1937. In 1930 the prolonged gas visitation of May 2, already discussed in connection with the larch, caused widespread markings on the more sensitive shrubs, such as ninebark, ocean spray and mountain laurel. Markings were also found on birch, aspen, hazel, service berry, bitter cherry and alder. The most widespread distribution of acute symptoms was on ninebark, of which marked plants were observed as far as about 36 miles south of the smelter. The elevations at which these markings were found decreased as the distance from the smelter increased. Thus, in the region of Scriver Creek, which flows into the Columbia on the east side, about 15 miles south of the smelter, the injured ninebark extended to an altitude of 2,800 ft. above sea level. Sixteen miles farther south the highest elevation at which markings were found on ninebark, as well as on ocean spray, was 1,900 ft.

Another gas visitation which caused extensive markings on the more sensitive broad-leaved trees and shrubs, in the region between the smelter and Northport, was that which occurred on June 26 and 27, 1930. Significant sulphur dioxide

concentrations were present for 31.3 hr. at the Stroh recorder station, with a maximum concentration of 0.92 p.p.m. The average concentration over the first 14-hr. period of fumigation was 0.390 p.p.m. and over the 17-hr. period, 0.315 p.p.m.

Severe injury to the leaves of apple trees was observed following a 24-hr. fumigation which occurred on September 21 and 22, 1930. The maximum concentration registered by the Stroh recorder was 2.11 p.p.m. and the average of the whole period was 0.437 p.p.m. It is interesting to note that at the Marble recorder, 14 miles farther south, the gas visitation lasted for 21 hr. with an average concentration over the period of 0.280 p.p.m. and a maximum reading of 0.93 p.p.m. However, no sulphur dioxide markings on the foliage of apple trees in this vicinity were found. The effect of this severe fumigation was not particularly noticeable on shrubs and broad-leaved trees, as most of the leaves had already begun to show the usual autumnal colorations and had begun to drop off.

With regard to acute symptoms on broad-leaved trees and shrubs during 1931, scarcely any injuries were observed in the zone between 10 miles south of Trail and Northport until after a prolonged fumigation of 31 hours' duration, during the period May 22-24, at the Stroh recorder station. The maximum concentration during this fumigation was 1.25 p.p.m. with an average of 0.21 p.p.m., and for a five-hour period the average was as high as 0.35 p.p.m. Acute markings of a slight nature appeared on ninebark as well as on sensitive crop plants.

Although gas visitations were quite frequent after the date of the above fumigation, it was only after the long gas visitation of June 14-16, which coincided with a period of rainy weather and high humidity, that acute symptoms on broad-leaved trees and shrubs were noticeably increased at the Stroh recorder station. This fumigation lasted 56 hr. with a maximum concentration of 0.67 p.p.m. and an average of 47.6 hr. of significant readings of 0.254 p.p.m. Markings on ninebark and birch were quite plentiful as far as Northport. The sulphur dioxide injury on ninebark disappeared in the vicinity of a point about seven miles south of Northport. No markings on either broad-leaved trees or shrubs were noticeable at Marble, where sulphur dioxide readings during the above-mentioned gas visitation were recorded for a total duration of 46 hr., with a maximum concentration of 0.41 and an average of 0.153 p.p.m. Markings on flowers were quite common in the gardens as far as Northport.

On the west side of the Columbia River the ninebark was found to be marked as far as a point about three miles south of Northport. Between Trail and Northport the bracken fern was severely marked and also service berry and, occasionally, the willow as well as other species.

During September 4 to 6 a sulphur dioxide visitation lasting for about 52 hr. at the Stroh recorder station caused fairly severe markings on the foliage of

apple trees. The maximum concentration during this gas visitation was 0.70 p.p.m. and the average about 0.20 p.p.m.

Whereas in 1930 injury to ninebark occurred nearly as far down the river as Bossburg, or about 26 miles below the border, in 1934 the injury faded out shortly below Northport, or about 10 miles below the border. There was a similar marked reduction in the lateral extent of injury. For instance, in 1930, sulphur dioxide injury was found on ninebark near Velvet, or about four miles in a direct line up from the mouth of Sheep Creek, but in 1934 injury could not be traced farther than one mile up Sheep Creek. Moreover, within these limits injury was very light in 1934, and even near the border one had to look carefully to find it.

On June 1, 1935, sulphur dioxide markings were found on ninebark and ocean spray close to the border, extending about two and one-half miles down the Columbia valley. At this point occasional markings were also noted on bitter cherry. After June 18, 1935, injury was found near the border on ninebark, bitter cherry, ocean spray, service berry, mountain laurel, dogbane, willow, birch, aspen and maple. Five miles south of this location the concentrations of sulphur dioxide measured at the Stroh recorder averaged 0.12 p.p.m. for 12 hr., with a maximum of 0.46 p.p.m. The next day another 12-hr. fumigation occurred, with a maximum concentration of 0.22 p.p.m. A slight amount of rain fell at the same time, so that conditions were ideal for injury. On the mountain-side, east of the above-mentioned location where injury occurred, markings were found on mountain laurel, maple, birch, bitter cherry and service berry, up to an elevation of 1,900 ft. Across the river at the same time markings occurred near the border on aspen and service berry. Counts were made to determine the percentage of trees or shrubs injured at several points in the valley. It was found that near the border on the east side of the river about 37% of the birch trees had been marked, with about 18% of the foliage affected; 16% of the maple and 19% of the mountain laurel were also marked. At a slightly higher elevation near this point, 22% of the birch were marked. About four miles south, 18% of the birch and 8% of the maple had been marked. This indicates that there is a decrease in the severity of injury as the distance from the smelter increases. On the west side of the river, 15% of the aspen had been marked, but only about 4% of the total foliage was injured.

Injury to shrubs was more extensive in 1936 than in 1935 owing to the more severe fumigations which occurred during the early part of May. As has been mentioned previously, ninebark (*Opulaster malvaceus*) is the most susceptible shrub to injury by sulphur dioxide. At the same time as the injury to larch occurred, this shrub was also damaged over a wide area. In general, it may be said that the area within which injury occurred to ninebark was not as extensive as that in which larch suffered damage. Damage to ninebark did not extend as far down the main river valley, as far up the tributary creek valleys, or as far up the mountain slopes as that of larch. In the main valley, injured nine-

bark was not found below China Bend (32 miles south of the smelter), and in the tributary valleys it did not extend nearly as far up as did injured larch. As for the other shrubs and broad-leaved trees, injury was observed near the border on birch, maple, bitter cherry, ocean spray, hazel, and mountain laurel, but the degree of injury was not as great as in 1935.

In Little Nigger Creek injury was found on ninebark, ocean spray, and birch up to an altitude of 2,550 ft. The other plants occurring here—hazel, alder, aspen, willow, maple, bitter cherry, and fireweed—were not affected. In the draw, about two miles south of the International Boundary on the east side of the Columbia River, injury was found up to about 2,400 ft. on ninebark, service berry, ocean spray, fireweed, bracken, white clover, larch, birch, and maple. On Big Nigger Creek no injury was noted except on larch, and this faded out at about 2,450 ft. elevation. Although in Deep Creek, Sheep Creek, and Onion Creek injury to shrubs did not extend far from the main river valley, markings on ninebark and ocean spray were found as far down the river as China Bend.

Reproduction of Conifers

In the course of the investigation into the question of injury to trees in the vicinity of Trail, B.C., attention was naturally paid to the matter of reproduction. In any region subject to smelter fumes there are several ways in which reproduction of trees may be adversely affected. These are as follows: (1) by a reduction of the amount of seed produced either by severe injury to the foliage or by the killing of trees; (2) by direct injury to the flowering organs; (3) by injury to the soil; and (4) by direct injury to the foliage of seedlings.

(1) In the Trail area, trees have been killed by sulphur dioxide for some distance, both up and down the river, and at greater distances there has been severe injury to the foliage without actual killing of the trees. In the area within which trees have been killed there has been an effect upon reproduction owing to the reduction in the amount of seed produced, while in the larger area in which severe injury to foliage has occurred there has been a similar, but less pronounced effect, owing to the fact that the amount of foliage has been reduced sufficiently to interfere with the synthesis of food materials necessary to the formation of seeds.

(2) In regard to injury to flowers by sulphur dioxide certain experimental work has been carried out to which reference will be made. In 1912 Sabachnikoff (14) studied the effect of various concentrations of sulphur dioxide upon the pollen of such species as *Hepatica*, *Narcissus*, *Viola*, *Orchis*, and *Crocus*. The method of study was to treat plants in flower with various concentrations of sulphur dioxide, then to remove the pollen and allow it to germinate in drops of saccharose solution. A concentration of 1:48,000 for 48 hr. was found to have no effect on germination, but 1:13,000 for three hours caused almost complete injury. A concentration of 1:13,000 for 24 hr. was considered to be the

limiting concentration necessary to prevent all germination of pollen. Pollen which was not killed germinated abnormally: the tubes remained short and assumed an irregular form.

In 1930 Arcichovskij (1) carried out some experiments which, while not applicable, have some bearing on the subject under consideration. Using pea seeds treated for two hours he studied the effect of various concentrations of sulphuric acid upon germination. Very dilute concentrations had practically no effect, then proportionately with increasing concentrations the toxicity of the acid increased at first until the maximum effect was reached at a concentration of $2N$. With higher concentrations the effect falls off quite sharply, probably owing to decreasing ionization. The range of concentration varied from $N/128$ to concentrated acid.

In 1931 Döpp (3) published the results of an extensive study of the effect of sulphur dioxide upon pollen and upon pollen germination. He pointed out that the effect of this gas on flowers may be direct or indirect. Indirect injury may be caused when the flowers themselves are not affected, but when the leaves are so severely injured that the food materials necessary for flower formation are no longer produced. Direct injury may occur in one of several ways. The sporophylls, also the micro- and macrosporangia, may be checked in different stages of their development and sooner or later destroyed, then the formation of normal grains and egg cells cannot take place. Mature pollen may be injured by gas, or a direct effect on the germination of pollen may occur. The tissues of the stigma and pistil may be injured so that the pollen tube cannot reach the egg cell. Further, an unfavorable influence by sulphur dioxide on the resulting fertilization is conceivable.

A variety of plants were used, among them being *Pinus montana*, *Pinus silvestris*, willow, oak, birch, maple, and alder. Air dry pollen was found to be much more resistant to gas than pollen which had been dampened. The humidity of the vessel in which the fumigation was carried out was a very important factor in determining resistance. Pollen placed on an artificial medium such as agar was much more susceptible than it was under drier conditions. In contrast to the effect of light in the presence of sulphur dioxide on green assimilating plant parts, it was found that in the case of pollen and pollen tubes light had no effect. Experiments with flowering shoots shortly before opening caused injury, which was expressed by a retardation of the opening of the flowers and anthers, by a reduction of the germination percentage of pollen, by decreased growth of pollen tubes, and by injury to the stigmata.

Several fumigations of pine pollen were carried out. Pollen of *Pinus montana*, fumigated with 10 p.p.m. for six days, the pollen being air dry and the air in the experimental vessel being of the humidity prevailing in the room in which the experiments were performed, was not affected by the treatment. Pollen of the same species fumigated for three days at 10 p.p.m., the pollen being

air dry but the air in the vessel being humidified, showed no effect. Also pollen treated at 10 p.p.m. for two hours, pollen and air both humidified, showed no effect. Pollen of *Pinus montana* and *Pinus silvestris* treated at 200 p.p.m. for 10 days, pollen and air both dry, gave 100% injury, i.e., no germination. The same result was obtained with the same species and the same conditions when the concentration was reduced to 1:15,000.

This study indicates that in order to cause injury to pollen it is necessary to use concentrations of sulphur dioxide of a very much higher order than ever obtain under field conditions. Direct injury to the reproductive organs of trees is not believed to occur in nature. Flowers are not absorbing organs as are leaves, so that it would naturally require very much higher concentrations to injure them. This is clearly shown by Döpp's experiments. In contrast to the high concentrations and long durations used by Döpp, the highest concentration recorded during the course of the investigation in the Trail area at the time of year when injury to flowers might occur was 1.25 p.p.m. for 10 min. The fumigation in question occurred on May 24, 1931, and lasted 4.6 hr. from 7.00 to 11.40 a.m., with an average concentration of 0.349 p.p.m. The only other concentration which exceeded 1.00 p.p.m. during the spring months occurred on April 22, 1933, when 1.30 p.p.m. for 10 min. was recorded. This fumigation lasted 2.5 hr., from 7.50 to 10.20 a.m., with an average concentration of 0.201 p.p.m. It may safely be concluded that in the Trail area reproduction of trees has never been adversely affected by a direct effect of sulphur dioxide upon the flowering organs.

In this connection a study of viability of yellow pine seed collected in the valley of the Columbia River in September, 1930, is of interest. Collections of seed were made at nine different locations in the area subject to sulphur dioxide; as controls, seed was also collected at five widely separated points outside the smelter area. In all cases composite samples of seed were taken, at least three trees being used. The germination tests were carried out in duplicate sets of 100 each, the period of each test being 40 days.

As may be seen from Table III, the average germination percentage of the control collections is 62 or, disregarding the Newport collection which is obviously subnormal, 68. The average of the collections in the area subject to fumigation is 69%, which is a very close agreement, and which indicates that under conditions obtaining in the Columbia valley sulphur dioxide has no influence whatever upon the flowers or seed of yellow pine.

(3) In regard to the indirect effect of sulphur dioxide on reproduction of trees by reason of injury to the soil, it may be said that no evidence of such an effect was observed in the field, but that the soil studies indicate that in the immediate vicinity of Trail such a result might be expected. However, in the limited area where soil acidity was found to be high enough to interfere seriously with growth there were very few trees, so that this influence of sulphur dioxide upon reproduction was negligible.

TABLE III
VIABILITY OF YELLOW PINE SEED

Locality	Date of collection, 1930	Germination, %
<i>Collections in Northport area</i>		
12 miles from Trail	Aug. 30	73
14 " " "	Aug. 30	51
15 " " "	Sept. 2	62
19 " " "	Aug. 30	64
21 " " "	Aug. 30	75
23 " " "	Sept. 1	76
29 " " "	Sept. 2	65
36 " " "	Sept. 1	81
42 " " "	Sept. 1	71
<i>Control collections</i>		
1 mile north of Cedonia	Sept. 3	61
8 miles north of Newport	Sept. 5	38
5 miles south of Kettle Falls	Sept. 3	75
Napoleon Bridge	Sept. 1	58
Daisy	Sept. 3	77

(4) During the course of the investigation a large number of plots were established to study the occurrence of reproduction in the area under consideration. Briefly, it may be said that seedlings were found to occur wherever natural conditions were favorable, *i.e.*, where there was a supply of seed and where favorable seed bed conditions obtained. Injury to the leaves of seedlings by sulphur dioxide was observed in 1930 about 11 miles down the river from Trail, in a small area of lodgepole pine reproduction, but although thousands of yellow pine and Douglas fir seedlings were examined at many locations throughout the area, none were found to be injured. In general, the reproduction observed was in excellent condition and making rapid growth.

A much more serious factor than sulphur dioxide in inhibiting reproduction was fire. While it is recognized that an initial fire is beneficial in promoting reproduction, yet a large proportion of the area under consideration has been repeatedly burned over, with disastrous effects upon reproduction. Besides the reduction in the amount of seed by killing of trees by fire, the seed bed is adversely affected by destruction of the duff and litter of the forest floor. When the humus layer is destroyed there are increased evaporation from the soil and less favorable conditions for germination and growth. In addition to forest fires it is a common practice in this area to set grass fires in the spring which, of course, destroy all small trees in the area burned over.

Cultivated Crops

Field Observations in the Trail-Northport Area. Owing to the rugged nature of the country along the Columbia River, cultivated land at present comprises but 2 to 3% of the total area in the smoke zone. Most of the farms are relatively small and are located on benches or terraces at different levels above the river, or on the sides or bottom of the valleys through which the tributary creeks flow. Forest lands which have been logged and burnt over provide considerable range for livestock in the summer months, and agriculture is, therefore, devoted largely to the production of winter feed. Alfalfa is the most important hay crop grown and, depending on precipitation, generally yields one good crop and a lighter second cutting. When irrigation water is available, three and sometimes even four cuttings are obtained in one season. Clover, timothy and other grasses are frequently grown for hay, particularly in the tributary valleys where moisture conditions are more favorable than in the main Columbia River valley. Cereals, such as winter wheat, spring wheat, barley, oats and rye, are grown to a limited extent and are generally harvested green for feeding purposes. Since much of the soil is low in water-holding capacity and periods of hot, dry weather are frequently present even in May or June of most years, the region is not so well adapted for the production of small grains, and crop failure is much more common with these than with alfalfa.

During seasons when the rainfall was insufficient and drought effects were severe, acute symptoms of sulphur dioxide injury on crops were relatively scarce in this area. This applies particularly to the year 1929 when the precipitation was only 9.60 in. for the entire year at Northport, Wash. The field observations point clearly to the dependence of injurious effects caused by the action of sulphur dioxide on weather conditions. It was generally found that acute symptoms of sulphur dioxide injury were associated with the period of the year most favorable to growth. On a susceptible species such as alfalfa acute markings very often occurred in the months of May and June when sulphur dioxide was present during periods of wet weather or when the humidity was high. During the months of July and August it was a rare occurrence to find sulphur dioxide markings even on alfalfa, although the concentrations of gas were frequently as high as earlier in the season. With the advent of rainy weather and conditions of higher humidity in September acute markings were again found occasionally where alfalfa was being grown under irrigation.

With crop plants a slight chlorosis caused by sulphur dioxide is difficult to separate from similar symptoms caused by other agencies, and it is important, therefore, to have certain selected plots which may be closely followed throughout their period of growth, and the appearance of all abnormal symptoms correlated with the occurrence of gas of known concentrations. During 1929, automatic sulphur dioxide recorders were not in operation, but from 1930 to 1937 a continuous record of gas visitations at the Stroh farm was available, also during part of this period at Marble and Northport. It has thus been

possible to correlate known sulphur dioxide concentrations with various markings which appeared on plots which were established at the Stroh ranch in 1930. Since most of the important crop plants were grown at this location a detailed description of the results obtained there, rather than from the general field surveys, seems worth while presenting.

During the last week in May, 1930, plots of Marquis wheat, Pellissier durum wheat, Pacific Bluestem wheat, Hannchen barley, Banner oats, Prolific rye, Crown flax and alfalfa were seeded on the Stroh plots. The sulphur dioxide recorder was not in operation until June 10, consequently the concentrations of sulphur dioxide which caused markings on June 7 are unknown. At this time the cereal plants were about 3 in. high and they had, in most cases, two leaves, although occasionally a third leaf was also present. Most of the marking was confined to the oldest leaves. Counts made on 1,000 seedlings of each variety showed that 25% of the barley was marked, 1.5% of durum wheat plants, 0.2% of Marquis and Bluestem wheat, whereas the oats were not injured. Rye suffered a few very slight markings. Three days later a fumigation lasting 5 hours and 40 minutes, with a maximum 20-min. reading of 0.83 p.p.m. did not cause any further marking on either cereals or alfalfa. Eight more fumigations occurred between June 10 and 26 without marking the plants. One of these, on June 20, lasted 13 hr., with a maximum concentration of 0.68 p.p.m. On June 26-27 a fumigation of 17.3 hr. duration occurred, with an average concentration of 0.315 and a maximum of 0.92 p.p.m., causing further markings on both cereals and alfalfa. Rye was marked most severely at this time, durum wheat next, followed by Marquis. Barley showed scarcely a mark, and the oats were entirely untouched. After this date, although there were occasional slight marks on alfalfa, no further symptoms of sulphur dioxide injury were ever noted on any of the cereals, and on the irrigated plots excellent crops were harvested in August. The dry plots suffered severely from lack of moisture and the crop on these was very light.

In 1931, plots of Marquis wheat, rye, oats, barley and alfalfa were grown beside the Stroh recorder. The cereals were not above ground before the 1st of June and consequently escaped several severe fumigations which caused injury to the alfalfa. A few marks were found on rye on June 1—in all about 10% of the plants showing slight symptoms. A further fumigation lasting 13 hr. on June 1, with a maximum concentration of 0.64 p.p.m. caused additional markings on the rye. Counts taken the next day indicated that 30% of the plants were marked. Further marking occurred on June 10-11 on the rye, and a few small white tips appeared on the barley on this date. A severe fumigation lasting 56 hr., with a maximum concentration of 0.67 p.p.m., occurred on June 14, 15 and 16. This was the longest, and possibly the most severe, fumigation which occurred during either growing seasons of 1930 or 1931. At this date the irrigated cereals were from 9 to 12 in. in height and showed the following percentage of marking: barley 17.4% of the plants with white tip

marks; rye, quite severely marked, many leaf tips marked for an inch or more, and over 90% of the plants affected; wheat, only a few small white tips; and oats, no sign of any injury. On June 20 another fumigation lasting for 12 hours and 45 minutes, although not as severe as the previous fumigation of 56 hr., caused more injury. Ninety-three per cent of the barley plants showed slight tip markings, and the effect on the rye was especially noticeable. The wheat and oats both escaped injury. After this date no further markings occurred on cereals on the Stroh plots.

In 1930 from June 10 to August 8, when the dry plots were harvested, the cereals were subjected to 54 fumigations of 424 hours' total duration, at an average concentration of 0.22 p.p.m. The irrigated plots were not harvested until August 20, so that they were exposed to 74 fumigations lasting 565 hr., at an average concentration of 0.21 p.p.m. The maximum reading recorded during growth of the plots was 0.92 p.p.m. for a period of 20 min.

In 1931, from the time of seeding on May 21 to harvest on August 21, there occurred 67 fumigations, totalling 525 hr. The average concentration was 0.185 p.p.m. and a maximum of 1.25 p.p.m. was present on May 24 for 20 min.

In 1934 the concentrations of sulphur dioxide were too low to cause marking on cereals on the Stroh plots at any time during the summer. Alfalfa was marked very slightly on three occasions—May 4, June 9, and July 16. The fumigation of May 4 lasted for 19.6 hr. with an average concentration of 0.210 p.p.m. and a maximum of 1.00 p.p.m. for one 20-min. period. On June 9 a fumigation occurred for four hours with an average concentration of 0.220 and a maximum of 0.65 p.p.m. The extreme sensitivity of alfalfa to sulphur dioxide is clearly shown by the slight markings which appeared a few days after the presence of gas at an average concentration of 0.220 p.p.m., from 5.40 p.m. to 12.20 a.m. on July 16-17, the maximum being 0.58 p.p.m. The three occasions listed above were the only times at which markings were found on any vegetation during the growing season in 1934. In 1935, although the duration of sulphur dioxide during the growing season was greater than during the corresponding period in 1934, markings on alfalfa were found in two fields only, close to the International Boundary in September.

In 1936 there were three occasions when sulphur dioxide caused markings on crops and garden plants. The first of these was on May 2, a day of high humidity, during which there was a 24-hr. fumigation with readings between 0.25 and 0.50 p.p.m., present for 5 hours and 20 minutes. Alfalfa, sensitive shrubs and larch were marked over quite a large territory at this time. On the Stroh plots 2% of the alfalfa leaves had slight acute markings; on a field of alfalfa near Northport 1.9% of the leaves were marked and five miles farther south in another field less than 1% of the leaves were injured. On most of the fields examined, less than 1% of the leaves of alfalfa were affected, and the

most severe marking did not exceed 2%. No acute markings were found on any of the cereals grown in the Northport area.

The markings in June, 1936, were very light, appeared on seedling alfalfa only, and extended over but a limited area. No markings were found on either the mature first crop of alfalfa, which was in flower at this time, or on the fresh young growth of the second crop. Sulphur dioxide was present for a period of 18 hr. on each of the two days, June 11 and 12, but there were only short periods when the concentrations were above 0.25 p.p.m. and they did not exceed 0.50 p.p.m. Since single fumigations of this order are not sufficient to cause markings on plants not previously exposed to the gas, these seedling plants must have been marked because of their long previous gas exposure in May and early June. The old alfalfa in flower was too resistant at this time to be marked, and the new growth, although quite susceptible, had not a high sulphate content and hence did not reach the critical point as quickly as the seedling alfalfa. On August 18, although the concentrations of sulphur dioxide recorded at the Stroh plot were low, and no markings occurred, five miles nearer the smelter at the boundary quite severe marking occurred on potatoes, carrots, squash, tomatoes, egg plant, castor oil plants, canteloupes, citron, grapes, apples, raspberries, lilacs, peaches, morning glory, and clover, as well as on native species such as *Ceanothus*.

Germination Tests on Cereal Seed Grown on the Stroh Plots

In both 1930 and 1931 after the plots had been harvested, samples of seed were sent to the Dominion Seed Branch Laboratories for official germination tests. In 1930 the Seed Branch Laboratory at Winnipeg, Manitoba, issued certificates showing the percentages of germination indicated in Table IV.

TABLE IV

Seed	Per cent germination
Marquis wheat from irrigated plot	96
Marquis wheat from dry plot	98
Durum wheat from irrigated plot	97
Durum wheat from dry plot	96
Bluestem wheat from irrigated plot	98
Bluestem wheat from dry plot	97
Banner oats from irrigated plot	97
Banner oats from dry plot	75
Hannchen barley from irrigated plot	100
Hannchen barley from dry plot	100
Prolific rye from dry plot	97

In 1931 the Seed Branch Laboratory at Toronto, Ontario, issued certificates showing the following percentages of germination:

TABLE V

Seed	Per cent germination without pre-chilling	Per cent germination with pre-chilling
Hannchen barley from irrigated plot	99	99
Hannchen barley from dry plot	100	98
Marquis wheat from irrigated plot	99	100
Marquis wheat from dry plot	98	100
Banner oats from irrigated plot	96	100
Banner oats from dry plot	91	100
Prolific rye from irrigated plot	99	98
Prolific rye from dry plot	98	97

The pre-chilling treatment consisted in keeping the seed for three or four days at approximately 7°C. before planting under regular conditions at 20°C. in order that the maximum germination might be evident. It will be observed that the germination percentages are very satisfactory. The dry oats appear to have benefited from the pre-chilling treatment to a slight extent. Possibly a similar treatment would have improved germination in the 1930 sample of dry plot oats also.

The results indicate clearly that the sulphur dioxide concentrations prevailing in the vicinity of the Stroh experimental plot during 1930 and 1931 were without effect on the germination of seed grown on this plot.

II. Symptomatology and Diagnosis of Sulphur Dioxide Injury of Forest and Crop Plants

Yellow Pine and Douglas Fir

In the area where the gas visitations were relatively severe and prolonged during the years 1929-30, the symptoms of injury were expressed as a reddish discoloration of the leaves with subsequent shrinkage of tissue and defoliation. The length of time between the occurrence of injury and the shedding of the damaged leaves varies greatly among the different species. In yellow pine it occurs slowly and in Douglas fir quickly. The discolorations occur without uniformity—at times the whole length of the leaf may be involved or again it may only be a limited area at the base, middle or tip of the leaf. The length of life of the leaves is greatly affected and in yellow pine, which normally retains its leaves for three years, only the current year's leaves, in general, are present (Fig. 1). It should be pointed out, however, that there are individual trees in this area which bear three years' heavy foliage (Fig. 2). These are trees which are resistant to the action of sulphur dioxide. Farther from the smelter where



FIG. 1. Yellow pine showing thin foliage due to sulphur dioxide—in the Columbia valley close to the International Boundary, November 11, 1934.



FIG. 2. Yellow pine in good condition with three years' heavy foliage—in the Columbia valley close to the International Boundary, November 11, 1934.

the gas concentrations are lower and less prolonged the resultant injury is naturally less pronounced in character. The reddish discolorations do not occur but the action of the gas is expressed by the partial destruction of the chlorophyll, with a consequent chlorosis or yellowing of the affected leaves.

These observations in regard to yellow pine also apply to Douglas fir. There is this difference, however, that unless examination is made shortly after injury has occurred it is much more difficult to detect, as, in general, fir leaves are shed soon after an injurious fumigation. Fir leaves are attached singly to the twigs by delicate petioles, which are readily injured by sulphur dioxide. By analogy it would be expected that a similar defoliation of injured leaves would occur in *Picea*—the spruces, in *Tsuga*—the hemlocks, and probably also in *Abies*—the true firs.

Of the above-mentioned species, fumigation experiments were carried out on yellow pine and Douglas fir growing in natural habitat at Summerland, B.C., in 1931. In the fumigation of conifers at Summerland it was found that the symptoms of injury on yellow pine differed from those on Douglas fir (Plates I and II), and even in the same species the symptoms of injury arising from winter fumigation were different from those noted during the growing season.

In winter the first indication of injury in yellow pine is a general loss of color from the normal dark green to a lighter shade of green. Following this, definite areas in the leaf turn to a yellowish-brown in marked contrast to the intervening areas of uninjured green tissue, giving the leaf a banded appearance which is very characteristic. In severely injured trees there is a gradual loss of the green color until all the foliage has become a pale yellow. With this change, of course, the banding of the leaf disappears. Then, depending on weather conditions, there is a progressive discoloration of the foliage from yellow to the reddish-brown which is the usual condition recognized as characteristic of sulphur dioxide injury to conifers. This change seems to be chiefly dependent upon light and to a less extent upon temperature. In itself it is, then, not a direct effect of sulphur dioxide injury but rather an indirect result. In the case of a plot which was fumigated during February and severely damaged, the leaves did not assume a reddish-brown color until about two months after the fumigation was stopped, and it was nearly three months before the leaves began to drop off. This shedding continued gradually in the most severely damaged trees until only the new foliage was left.

Another symptom of injury noticed was that a definite pungent odor was always detected immediately after the removal of the cabinets from plots which contained severely injured trees. This odor was not noticed except in cases where severe injury had occurred.

The principal distinction observed between the effects of winter and summer fumigation of yellow pine was the length of time taken for the color changes in the foliage to develop. In summer there was at first a similar loss of the



Yellow pine leaves showing injury by sulphur dioxide in the distal part of the leaves. This type of marking is more common during the summer.



Yellow pine leaves showing the banding effect sometimes produced by sulphur dioxide. This type of injury may be produced by prolonged treatment with sulphur dioxide in high concentrations such as 5.0 p.p.m. in winter during mild weather when the temperature is abnormally high.

normal green color followed by the appearance of the bands noted during the winter experiments. The discoloration progressed more rapidly, however, the injured leaves assuming the characteristic red-brown shade in about a week. Defoliation did not occur very much sooner after injury in summer than in winter.

An attempt was made to define the color changes occurring in injured leaves, but because the injured areas were not always uniform in color and because the discolorations varied on leaves of the different years, this was difficult to do exactly. However, it was found that in yellow pine the first discoloration in leaves of the current year was uniformly buff, varying from warm, to cream, to light ochraceous buff (13). This discoloration gradually became more pronounced until about a week afterwards it had changed to a cinnamon buff (13). In about six weeks the discoloration had deepened to Sanford's brown (13). From then on the color either remained the same or became a little less pronounced until the affected leaves were shed.

In the case of Douglas fir, the first symptom of injury in the winter was a general fading of the green color of the leaves. Except for an occasional slight suggestion of banding there was no further discoloration of the leaves other than at the petiole. Here there was a change in color, first to pale yellow and then to reddish-brown (Plate II). This change was first observed about one to three weeks after the fumigation was stopped. At this time the leaves were being shed though still green and, upon superficial examination, apparently uninjured. If touched by hand or disturbed by wind they would fall off freely. To the touch it seemed as though injured fir leaves were less resilient than normal leaves. This might be accounted for by loss of water, making the leaves stiffer.

In Douglas fir foliage injured during the growing season a general loss of the green color was the first symptom of the effect of sulphur dioxide. In one case it was found that the normal color of the current year's leaves was cress green (13), whereas injured leaves had faded to serpentine green (13). The normal shininess of the upper surface of the leaves largely disappears upon injured foliage, giving a mat effect. In addition, there is also a much more pronounced banding effect than occurs in winter, though it is not nearly as marked as in yellow pine. Frequently there is considerable tip injury or the discoloration may be confined to the central part of the leaf. Basal injury is characteristic of summer, as of winter, injury, but in a few cases it was observed that this type of injury did not seem quite as uniform as in the winter. On some of the plots, leaves which had been injured in the central or upper part persisted upon the tree and were not shed. However, injured leaves generally were shed shortly after a damaging fumigation.

Several examples of recovery from the effects of sulphur dioxide concentrations just sufficient to cause a slight chlorosis of the leaves were noted during

the course of these fumigation experiments. As far as one could tell, such border-line cases of sulphur dioxide injury had resulted in the loss of some of the chlorophyll, but had not apparently injured any of the leaf cells. Under favorable conditions when only the chlorophyll had been affected, the leaf possessed the power to replace the lost chlorophyll to a very remarkable degree.

In the field, owing to the shedding of needles shortly after injury, it is difficult to detect sulphur dioxide injury unless examination be made very shortly after the damaging fumigation. However, Douglas fir trees which have been injured by prolonged low concentrations of sulphur dioxide assume certain characteristics which make the diagnosis of the condition fairly conclusive. Such a tree is shown in Fig. 3. It will be noted that for the most part the branches are dead at the extremities and that the foliage which is present on the tree is confined to those parts of the limbs adjacent to the trunk. Here it is abnormally dense, suggesting the witches' broom formation caused by certain fungi. The foliage is also much reduced in amount, only one or two years' leaves being present instead of the usual four to five or more.



FIG. 3. *Douglas fir showing injury due to sulphur dioxide—in the Columbia valley about four miles south of the International Boundary, September 6, 1934.*



Sulphur dioxide injury in Douglas fir. In this specimen a considerable amount of defoliation has already occurred. Fir leaves are attached singly to the twigs by delicate petioles which are readily injured by sulphur dioxide, and they are generally shed soon after an injurious fumigation. Yellow pine leaves, on the contrary, are arranged in clusters of three, the bases of which are enclosed in sheaths formed by the bud scales. On account of this strong attachment yellow pine leaves persist for a long time, even after the most severe injury.

Other Conifers

With regard to the other coniferous species, such as red cedar, white pine, hemlock, Engelmann spruce, grand fir and lodgepole pine, acute symptoms of sulphur dioxide injury were rarely found in the area under investigation. Lodgepole pine is the only one of these species present to any great extent in the main valley of the Columbia where sulphur dioxide is likely to occur in significant concentrations. However, owing to the resistant character of this tree, it seldom showed acute markings. From experiments at Summerland, B.C., it was evident that acute symptoms on this species were very similar to those observed on yellow pine, but the subsequent development of color of affected leaves became a more pronounced reddish-brown. As in yellow pine, injury occurs in bands and on the tips of the needles. At the junction between the dead and living tissue a definite dark line is generally present.

The symptoms in white pine are similar to those in yellow pine, except that the final color, when the affected needles have dried out, is not as deep a hue. The acute symptoms in hemlock are confined to the distal portion of the leaf and the discolorations are light brown and sharply cut off from the uninjured area.

Western red cedar is quite resistant to the action of sulphur dioxide, and no acute symptoms were observed in the field except relatively close to the smelter. It frequently suffers winter injury which may be readily confused with sulphur dioxide markings. In the few plants which were present in the experimentally fumigated plots at Summerland, markings were confined to the tips of the new leaves and were reddish-brown in color. Owing to the minute scale-like structure and mode of attachment of the leaves in cedar, the injured parts persist for a long time after death.

Symptoms on Engelmann spruce are very similar to those already described for Douglas fir. The discolorations are of a greyish-brown, rather than reddish-brown, shade. The shedding of the needles is very pronounced on the foliage affected by sulphur dioxide.

In grand fir the markings as observed from experimental fumigations appear as definite clear-cut discolorations on the tips of the leaves and sometimes on the central portion. The markings assume a reddish-brown color after the tissue has dried out.

Discolorations of Conifers not Caused by Sulphur Dioxide

Conifers, broad-leaved trees, and shrubs are all subject to various types of injury to foliage, some of which can be readily diagnosed, while others resemble symptoms of sulphur dioxide injury so closely that it is impossible to determine the cause by an examination of the specimen alone. The principal factors which cause foliage injury to coniferous trees and shrubs are winter injury, drought, disease, insects, and fire.

Winter Injury. There are two principal types of injury in conifers caused by certain weather conditions during the winter. These are red belt and winter injury, the former being the more severe. In red belt the injury is often confined to the older leaves, the younger foliage remaining green and persisting on the trees. In other cases the damage is much more pronounced, all the foliage and many twigs and branches being involved. Trees affected in this way generally die the following season. There is a tendency for injury of this type to occur on exposed mountain sides, in bands or belts, which lie parallel to the contour lines, although the injury may occur irregularly with little or no suggestion of banding. In winter injury, which is probably only a milder form of red belt, the discoloration of foliage is usually confined to the leaves of the last year or last two years. Occasionally, however, all the leaves may be involved. A few instances in which branches or twigs were killed have been observed but this is unusual.

In both red belt and winter injury the affected foliage turns a bright reddish-brown shade which gradually fades. When the leaves are only partly affected the injury is almost always confined to the distal portion of the leaf. In both types of injury the symptoms are most pronounced in trees with a southern exposure and in isolated trees, or trees in an open stand, rather than in those in a close stand. In the spring of 1936, however, severe winter injury was observed in northern Idaho in a heavy stand of larch, yellow pine, Douglas fir, lodgepole pine, white pine, and grand fir. In both types, too, when the lower limbs are covered by snow they remain green and unaffected.

The direct cause of killing of foliage both by red belt and winter injury is apparently a deficiency of water in the leaf tissues, brought about by transpiration at a time when the water given off cannot be replaced owing to the fact that the limbs, trunk, and at least part of the root system are frozen. This condition arises as a result of rapid changes in temperature during the winter. A period of very cold weather is sometimes followed by a sudden rise in temperature accompanied by sunny weather and warm drying winds. The leaves are stimulated into activity and sufficient transpiration occurs to exhaust the available water supply. Death of the foliage follows as a result of its being dried out.

No instances of red belt were observed in the Columbia valley during the course of the present investigation, but winter injury in coniferous evergreens, principally yellow pine, occurred to some extent each year, and was particularly pronounced in the winters of 1929-30, 1935-36, and 1936-37. No other type of marking in evergreens resembles acute injury caused by sulphur dioxide as closely as does that produced by winter injury. The two types of injury are so similar in appearance that it is impossible to distinguish between them by an examination of specimens alone. It is only when all relevant circumstances, such as sulphur dioxide and meteorological records, appearance of trees in areas

beyond the influence of sulphur dioxide, and distribution of injury among the leaves of different years are taken into account that a decision can be made.

Drought. In a semi-arid region, such as the Trail area, where the annual precipitation of about 15 in. is just sufficient to maintain growth, there is a continual struggle among plants for soil moisture. In such an area precipitation is the limiting factor in regard to the occurrence and growth of plant species. On exposed sites, with thin soil, the vegetation shows the effect of drought each year, and in years in which the precipitation falls below normal, vegetation generally is affected.

Among conifers, lodgepole pine was the species most severely affected by drought. In 1929 when the precipitation amounted to less than 10 in. following a year in which the total rainfall had also been below the average, widespread and pronounced injury occurred on young trees of this species. During the month of July, when no rainfall whatever occurred, the foliage of many young trees in an area of reproduction near Northport became chlorotic. By September the color of the leaves had changed to a reddish-brown; the extremities of the leaders and many branches had assumed a twisted form and many trees were dead. By December the mortality had greatly increased, thousands of trees having died. Though this particular location was within the area subject to gas visitations, the same type of injury was observed at many points far beyond the influence of the sulphur dioxide, so that it was clearly evident that the injury was in no way connected with the occurrence of gas. While lodgepole pine was the species most severely injured, other trees, such as Douglas fir, yellow pine, cedar, white pine, and grand fir showed similar effects. For the most part this injury was confined to small trees although an occasional large individual was affected. Again, in the late summer of 1934, drought injury occurred in lodgepole pine and to a slight extent in Douglas fir and yellow pine. The last two species require less soil moisture and humidity in the air than does lodgepole pine. As previously, the same type of injury was found in these species in locations far removed from the influence of sulphur dioxide.

Another effect of insufficient precipitation on conifers is the premature discoloration and shedding of old leaves. This was noted in lodgepole pine, yellow pine, white pine, and cedar. In dry years the oldest leaves, which would have been shed normally in the fall, began to turn yellow about the end of June, and to fall off during the late summer.

Drought effects also occurred in broad-leaved trees and were manifested by discolored, intercostal areas and by premature defoliation. These symptoms were noted in aspen, maple, birch, willow, and cherry.

In shrubs, too, the effects of insufficient moisture were apparent each year. Every year during the course of this investigation, ninebark, one of the most common shrubs in the area under study, on exposed sites was the first species to show premature autumnal discoloration, the date of the appearance of the

first symptoms varying with moisture conditions. In the very dry summer of 1934 the leaves of ninebark, on exposed sites with thin soil, began to show a reddish tinge towards the end of June. Usually, however, this change was not observed until about the middle of July, but from then on the reddening of the leaves gradually became intensified until by late summer the mountain sides were brilliant with the discolored foliage of this shrub. That this condition bore no relation to sulphur dioxide injury was proved by the occurrence of the same symptoms at the same time in areas remote from the influence of the sulphur dioxide. It was further shown by the fact that in the area subject to fumigation, individual ninebark plants, growing in localized areas where the soil moisture conditions were favorable, remained green until the latter part of September. Moreover, the distribution of the affected plants within the region subject to fumes was not such as to suggest the influence of gas. If there had been any relation between the premature discoloration of ninebark and the presence of sulphur dioxide, it might reasonably have been expected that the symptoms would be more pronounced near the source of gas, where the duration and concentrations would be greatest, but this was never observed to be the case.

Premature discoloration and defoliation were also observed in other shrubs such as hazel, ocean spray, and service berry.

Disease. Owing to the dry conditions of the Columbia valley not many diseases caused by fungi were observed, although along the creek bottoms and at upper elevations where moisture conditions were more favorable a few rusts of conifers were noted. In larch, the needle cast fungus (*Hypodermella laricis*) was found to occur in certain tributary valleys and at upper elevations in the main valley, where it caused considerable damage in years when weather conditions were favorable to its dissemination. This parasite attacks the foliage, infection occurring in the spring as soon as the new leaves appear. The first symptom is the appearance of small yellowish areas in the leaves, followed by wilting. The leaves gradually lose their green color and assume a light reddish-brown shade. Later, black oval to oblong fruiting bodies appear on the upper surface of the leaves. Infected leaves persist until the following year when the mature ascospores are discharged and the life cycle begins again. When the infected leaves change to a reddish-brown shade the symptoms closely resemble those caused by sulphur dioxide. However, this disease was never observed in the area subject to fumigations.

A disease of larch of more common occurrence was the chlorosis known as larch yellows. The principal symptom of this disease is a complete yellowing of the foliage followed by premature defoliation. The general appearance is about the same as that assumed by healthy larch in early autumn, when the leaves turn yellow preparatory to being shed. Occasional trees were observed in which the foliage was mottled with alternate green and yellow areas, but this condition is believed to be a variation of the usual type of yellows. Larch

yellowings was observed each year in the Trail area during the course of the investigation, but of more frequent occurrence in years of low precipitation. Since the initial symptoms of this disease generally appeared during the latter part of July and as the result was premature defoliation, there must have been an adverse effect upon growth.

As with the premature discoloration of ninebark, the distribution of larch yellowings in the Trail area was not such as to suggest a possible relation with the occurrence of sulphur dioxide—the first trees affected were usually found 25 to 35 miles from the smelter in the main river valley. Further, in locations much nearer the smelter, larch trees growing in soil well supplied with moisture remained green until the fall. In addition, larch yellowings occurred not only in that part of the Columbia valley subjected to gas visitations, but also was widespread in northeastern Washington and southeastern British Columbia. In those areas beyond the influence of sulphur dioxide, yellowings occurred as early and extensively as within the Columbia valley.

Larch yellowings does not appear to have been mentioned in the literature, although chlorosis of a number of other conifers, such as yellow pine, lodgepole pine and Douglas fir, has been recognized. In forest nurseries in Nebraska and Idaho this condition has been corrected by spraying the infected stock with a 1% solution of ferrous sulphate, at intervals of 10 days. The cause of chlorosis is unknown, but it is thought to be a deficiency of some essential mineral element.

In the case of larch yellowings it was apparent that the occurrence of the disease was intimately related to drought conditions. It was suspected that the condition was possibly related to a deficiency of some mineral element, and a large number of experimental treatments of affected trees were made in the fall of 1936. These included both injections into the trunk and application to the ground beneath the tree. The following chemicals were used: boron, magnesium sulphate, potassium sulphate, zinc sulphate, copper sulphate, manganese sulphate, and ferric ammonium citrate. An examination of the trees in 1937, however, failed to show any positive results.

Insects. While discoloration of coniferous foliage may be caused by certain insects, it is generally not difficult to distinguish such effects from those produced by sulphur dioxide. As a result of infestation by bark beetles the entire foliage of small or mature trees gradually becomes discolored and later the trees die. Discoloration of individual leaves is brought about by aphids or leaf miners. In the general area under consideration severe damage was caused to Douglas fir over a period of several years by the tussock moth, an insect which feeds upon the leaves. In some areas all Douglas fir were killed, while in others many trees were partially defoliated.

Fire. Fire is frequently the cause of thin or discolored foliage in conifers. This condition may arise either directly, by the foliage being destroyed by fire

or heat, or indirectly, by severe damage to the trunk, so that the physiological processes are affected.

While the former result, of course, gives rise to reddish-brown discolorations in the leaves there is no possibility of confusing these with symptoms produced by sulphur dioxide. The latter condition, however, often causes trees to appear as if suffering from chronic injury by sulphur dioxide, and as time passes the evidence of fire injury becomes less conspicuous. The factor of fire has also been considered under the section devoted to a consideration of the effect of sulphur dioxide on reproduction.

Symptoms on Broad-leaved Trees and Shrubs

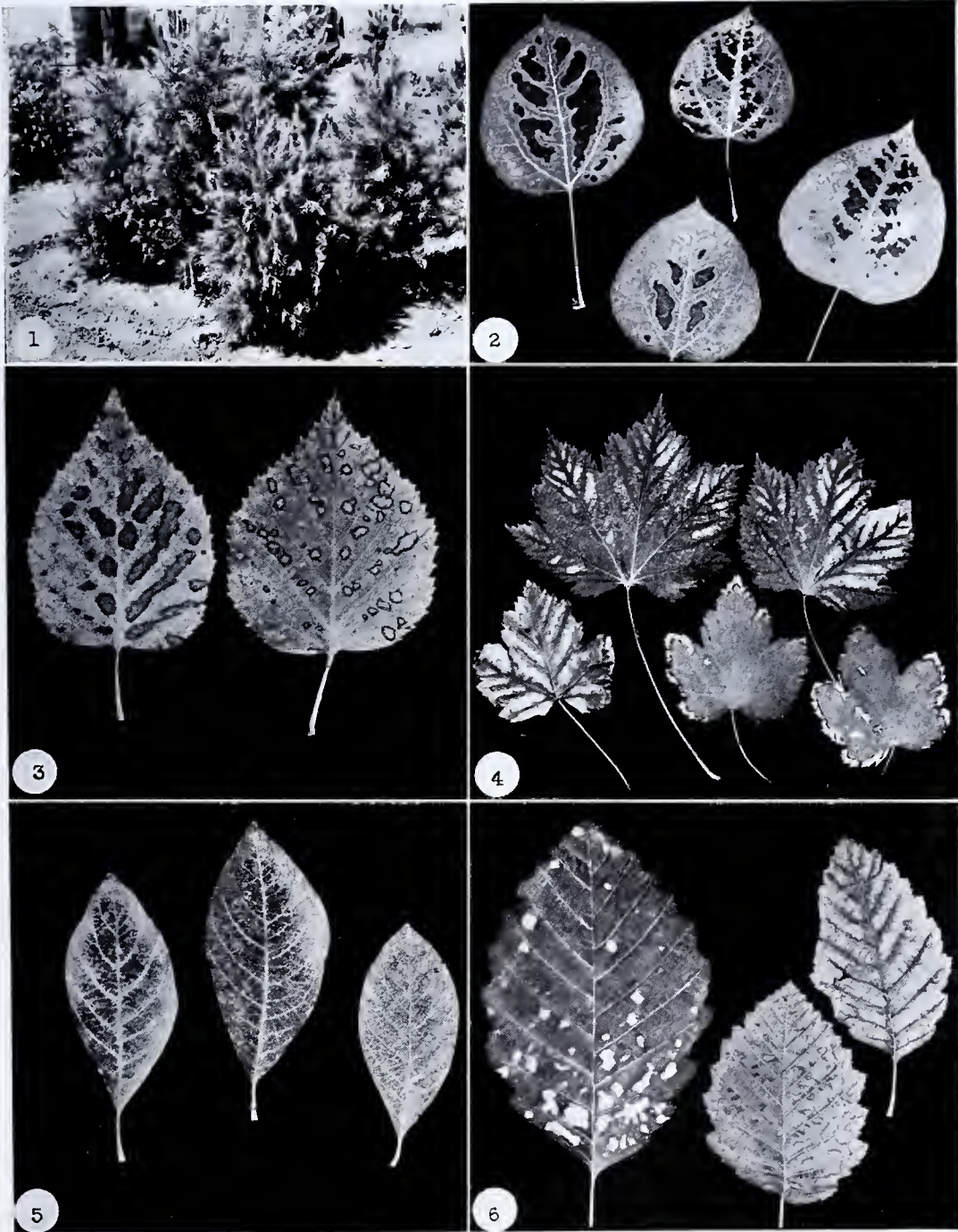
Because of the wide variety and shape of the leaves of broad-leaved deciduous trees there is naturally a much greater opportunity for the expression of many different symptoms of acute sulphur dioxide markings. Although these are usually intercostal or marginal on the leaves there are certain distinctive features present in the different species which are worth while describing. A few of these symptoms on aspen, birch, maple, willow and alder are shown in Plate III, on service berry, ninebark, dogbane, mountain laurel, dogwood, hawthorn, and mock orange in Plate IV, and apple, hazel, raspberry, grape, and chokecherry in Plate V.

On birch the markings were usually intercostal although, where injury was severe, marginal markings were not infrequent. The color at first was a very light brown, which in a few days became intensified and reddened. Usually the intercostal areas killed by sulphur dioxide consisted of numerous small spots with a very definite margin, and these sometimes coalesced to form elongated killed areas between the main veins. (Plate III, Fig. 3.)

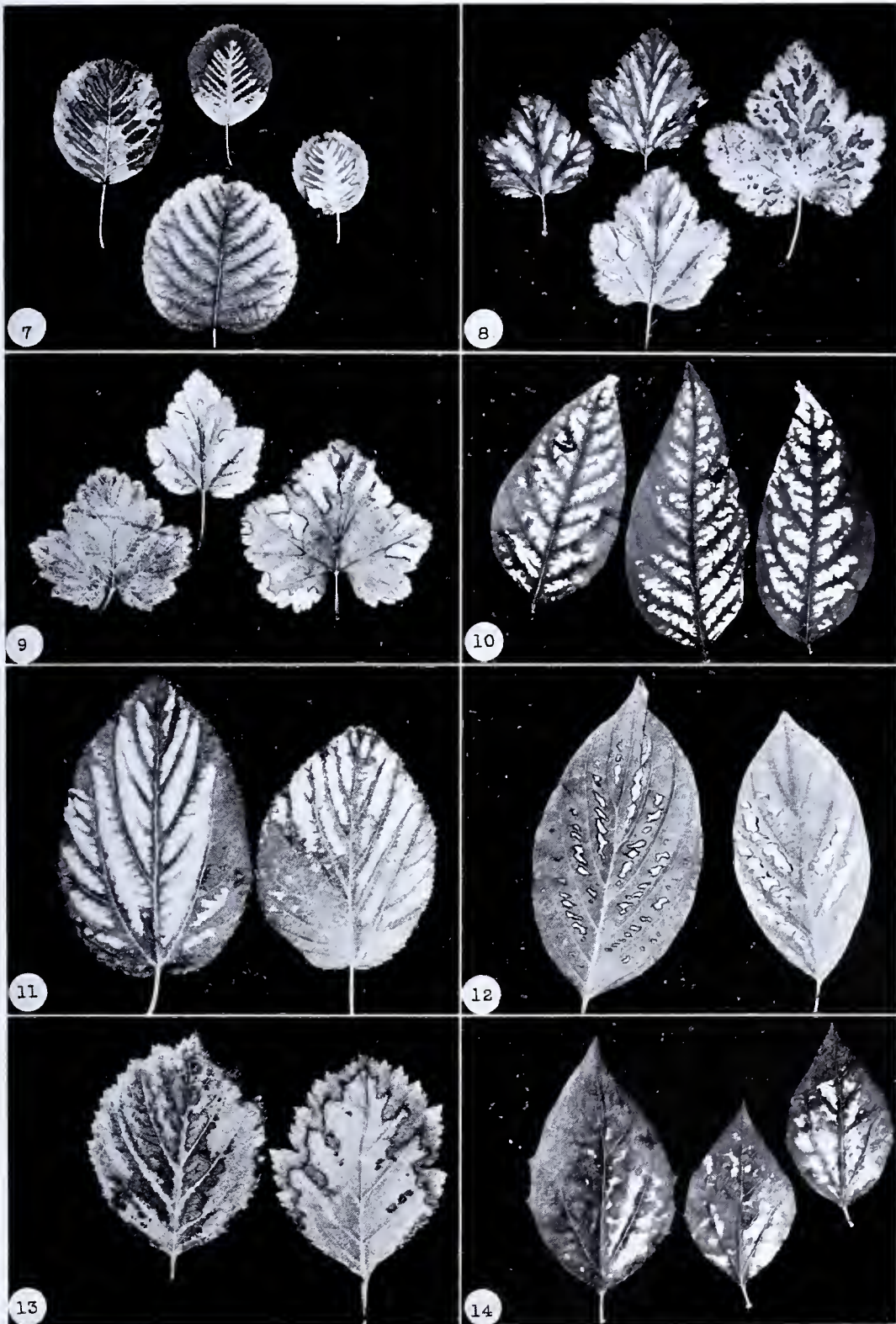
In the case of aspen, where injury was severe, frequently all the tissue in the leaf, with the exception of a small strip along the mid-rib, was killed. Where injury was less severe the markings had a tendency to lie between the main side veins in the mid-rib, forming definite, regular, killed areas. Shortly after injury occurred the color of the acute markings was light or reddish-brown, which frequently became almost black later in the season. (Plate III, Fig. 2.)

Maple is fairly resistant to sulphur dioxide but markings were found occasionally. Usually they were marginal, extending down deep between the veins of the leaf. Occasionally there were a great number of very small intercostal areas killed. In this species the color is usually a very light brown and there is no tendency to turn red on aging. Frequently at the junction between the killed and healthy tissue a dark water-soaked margin is present. (Plate III, Fig. 4.)

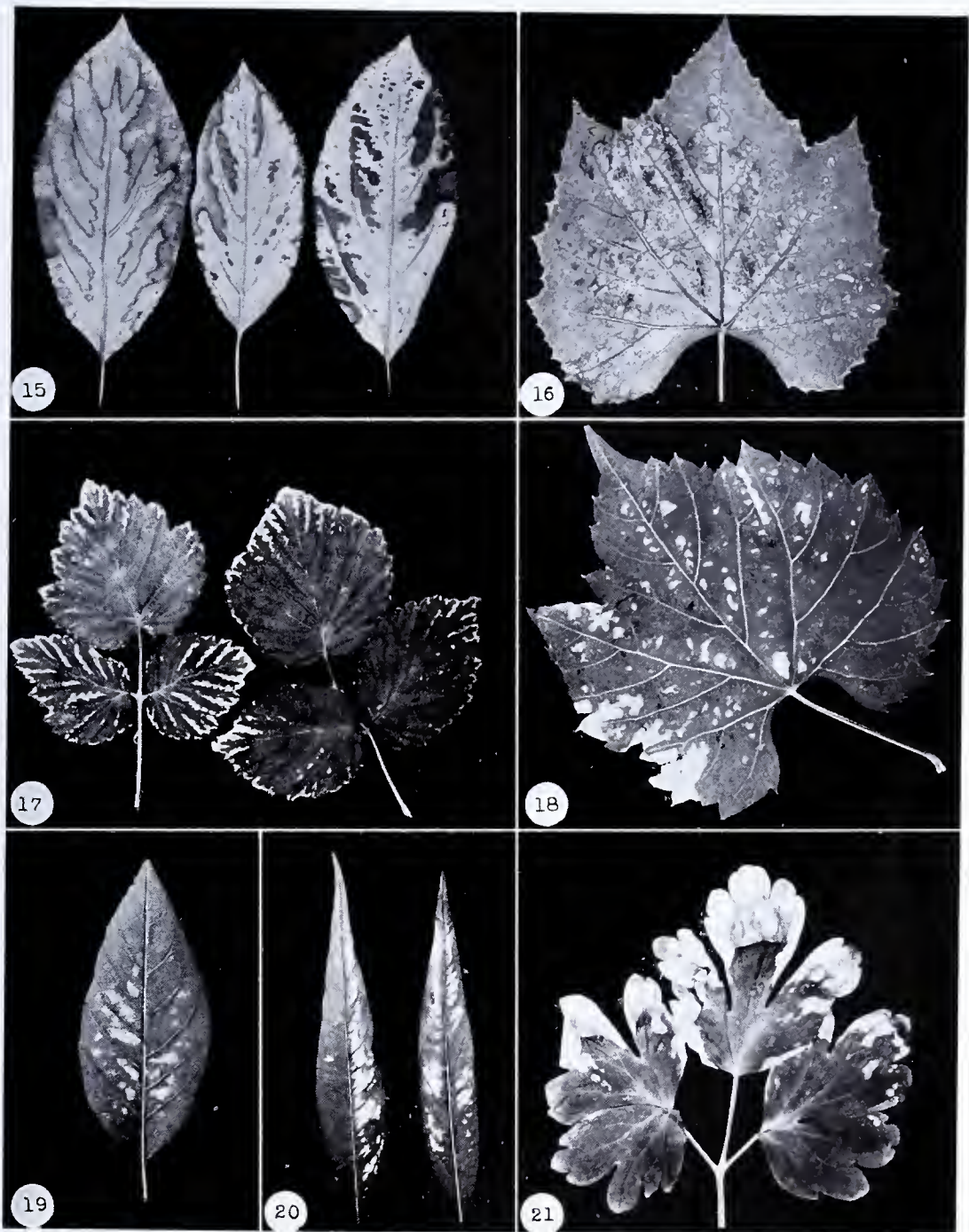
In willow the markings are much more apparent on the upper than on the lower epidermis and are of a diffuse character. They have a tendency to follow



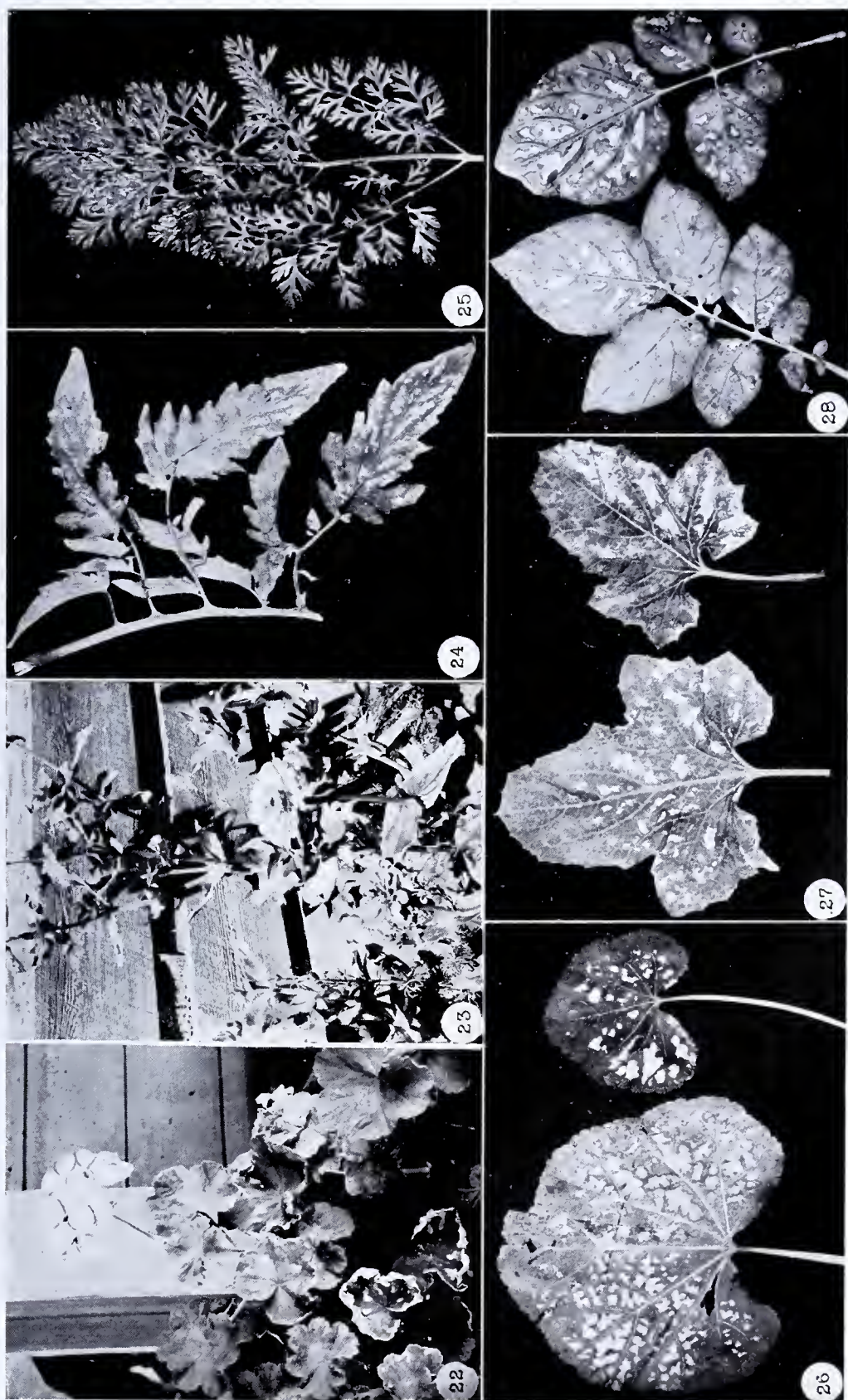
Symptoms of sulphur dioxide injury. FIG. 1. Larch. FIG. 2. Aspen. FIG. 3. Birch. FIG. 4. Maple. FIG. 5. Willow. FIG. 6. Alder.



Symptoms of sulphur dioxide injury. FIG. 7. Service berry. FIGS. 8 and 9. Ninebark. FIG. 10. Dogbane. FIG. 11. Mountain laurel. FIG. 12. Dogwood. FIG. 13 Hawthorne. FIG. 14. Mock orange.



Symptoms of sulphur dioxide injury. FIG. 15, Apple. FIGS. 16 and 18 Grape. FIG. 17, Raspberry. FIG. 19, Bitter cherry. FIG. 20, Fireweed. FIG. 21, Columbine.



Symptoms of sulphur dioxide injury. FIG. 22, Geranium. FIG. 23, Zinnia. FIG. 24, Tomato. FIG. 25, Carrot. FIG. 26, Hollyhock. FIG. 27, Squash. FIG. 28, Potato.

the mid-rib in the main veins and seldom appear on the edge of the leaf. The color is a very deep reddish-brown which fades out imperceptibly into the normal green of the leaf. (Plate III, Fig. 5.)

The markings on alder are quite similar to those found on birch, being sharply intercostal, frequently marginal, and extending down between the side veins. At the time of injury the color is light brown, but on aging the symptoms become a deep red. (Plate III, Fig. 6.)

Almost without exception, on *Amelanchier* the markings occur on the margins of the leaves and, where severe, cover the whole distal part of the leaf, only the mid-rib and main veins remaining green, and these stand out as jagged lines in the bright, reddish-brown killed tissue. (Plate IV, Fig. 7.)

Ninebark was one of the most susceptible plants to sulphur dioxide injury, and in the spring months was one of the most useful indicator plants. It grows in a wide variety of sites and on poor, rocky soils, frequently begins to dry up and discolor quite early, although on sheltered sites it remains green throughout the summer. Sulphur dioxide markings are quite characteristic on this species and are seldom liable to be confused with other symptoms. The color is bright brown, when fresh, becoming reddish-brown with age and frequently edged with a dark border. Both marginal and intercostal markings occur, but they seldom lie close to the veins of the leaf. (Plate IV, Figs. 8 and 9.)

On all the specimens of dogbane collected with leaves marked by sulphur dioxide, the killed areas were intercostal and very sharply cut off from the uninjured parts. The color was at first a dull grey, later changing to a light red-brown. (Plate IV, Fig. 10.)

Mountain laurel has smooth shining leaves with prominent veins, usually very free from discoloration of any kind. It is quite sensitive to injury by sulphur dioxide, and the bright brown injured areas, which generally extend down between the veins in long narrow bands, contrast sharply with the bright green of the uninjured parts. (Plate IV, Fig. 11.)

Dogwood is very resistant to injury by sulphur dioxide but, where markings did occur, they were in the form of small irregular intercostal spots, light brown in color, ringed with a dark edge. (Plate IV, Fig. 12.)

On hawthorn the markings were nearly always marginal toward the tip of the leaf and these became a deep reddish-brown with age. (Plate IV, Fig. 13.)

The markings on mock orange were intercostal and generally they were most numerous near the base of the leaf. The color was very light at first, almost white, becoming brownish-grey with age. (Plate IV, Fig. 14.)

Sulphur dioxide markings on apple leaves are very similar to the discolorations which appear on senescent leaves in the fall. The markings are usually marginal, extending in broad bands down between the veins almost to the mid-rib.

Intercostal markings may also occur. The color is light brown, becoming duller, and dark with age. (Plate V, Fig. 15.)

Symptoms of Sulphur Dioxide Injury on Alfalfa and Cereals

At Summerland, B.C., fumigation experiments were carried out in 1931 on barley, in 1935 on winter wheat, barley and alfalfa, and in 1936 on alfalfa. As a result of this work, during which numerous plots were fumigated under a wide range of environmental conditions and sulphur dioxide concentrations, with control plots close by for comparison, there was an excellent opportunity to make a careful study of all the different types of markings and discolorations encountered. Since there were no differences found in the symptoms produced by sulphur dioxide on wheat or barley, a detailed description of the barley will be sufficient and can be applied to cereals generally.

Description of Markings on Barley. On monocotyledonous plants such as cereals, where the leaves are parallel-veined in contrast to the net-veined type found in a dicotyledon like alfalfa, it is to be expected that certain distinct differences should result in the types of markings produced. In reality this is the case. The symptoms on barley are less confusing and tend to follow certain regular, well defined patterns more so than on alfalfa. The markings found on barley may be classified as follows:

I—Acute Injury

- (a) The concentrated or "kill back" type. This may involve a whole leaf but generally affects only the tip and is a total killing of the tissue for a definite region back from the tip of the leaf.
- (b) The mottled or spotted type.
- (c) The banded type.

II—Chlorotic Injury.

First symptoms of acute injury are slightly flaccid areas of diffuse greyish-green coloration. On observation of these areas under the microscope the chlorophyll appears to diffuse from the chloroplasts into the rest of the cytoplasm in the cells. At this stage very little shrinkage of the vacuole has taken place, and there is no detectable injury to the protoplasm lining the cell wall. The plastids still retain their shape. This greyish-green color will persist for some time if the leaf is protected from the light. In the presence of sunlight a rapid desiccation of the affected area takes place, accompanied by a great shrinkage of the cell contents. The leaf gradually assumes a bleached, whitened appearance, due to the decomposition of the chlorophyll.

The cotyledons after emergence are fairly resistant but if they are marked the injury will usually be confined to the tip or edge of the leaf. Then as the

plant reaches the fifth or sixth leaf stage most of the marks will be found on the middle-aged leaves. With age it will become increasingly difficult to mark the older leaves. In general, as long as the seedling is small enough and the leaves have a tendency to remain erect rather than droop over, the "kill back" type of marking will be of common occurrence. The tips of the leaves and areas which may extend down the side of the leaf from the killed tip will be affected in the case of the seedlings as shown in Plate XVIII. The tips of the leaves will curl and shrink after injury. When the plant reaches the shot-blade stage, although the "kill back" acute markings are still the most common on the broad leaves, the spotted or mottled type and the banded markings may be found. The spotted markings lie between the mid-rib and the edge of the leaf and usually extend farther in the longitudinal than in the lateral direction on the leaf. In some cases there may be a mottled effect due to the persistence of "green islands", isolated areas surrounded by killed tissue. The most susceptible spot on the large overhanging leaves found at this stage of the growth of the plant is not the tip, but the part exposed to the direct rays of the sun, that is, right where the bend occurs. Frequently there will be a spot injured here, or, occasionally, a band right across the leaf, causing the whole upper part of the leaf to die.

It has been observed that when barley is in the shot-blade stage, the basal part of the leaf, below the ligule surrounding the head, is one of the most susceptible parts of the plant to sulphur dioxide injury. Frequently it will be severely marked when the tip of the blade is free from injury or only has a slight tip marking. A little later when the heads have emerged, the upper leaves, the awns and the glumes exhibit about equal susceptibility. The awns are most frequently marked on the extreme tips, but they may show very sharp bands. In some instances there have been noted four or five bands where the chlorophyll has bleached out and the areas between are still green. The spikelets usually mark near the tip, although where injury is severe the whole spikelet may be affected. The lateral spikelets usually are more severely injured than the central fertile spikelets.

Chlorotic injury has often been called chronic injury, but since the latter term seems to apply particularly to certain effects found on coniferous trees it seems advisable to use the term "chlorotic" for those injuries on barley where there is no killing of tissue, but only a paling of the normal green of the chlorophyll. This paling may vary greatly in degree and is apparently of two types, temporary and permanent. The temporary chlorosis was noticed in the case of a prolonged treatment with 0.30 p.p.m. of sulphur dioxide. The fumigated plot, as a whole, assumed a light green or yellow-green color when compared with the control plot. This condition was noticeable for some time after fumigation, but gradually disappeared in about two weeks. The leaves did not lose their turgor and continued to function, though possibly below normal, for growth was slightly retarded. Although fumigated plots where no acute mark-

ings occurred were compared with control plots to see whether there was an appreciable amount of chlorosis or earlier maturation of the older leaves, no differences were found in this respect. There was no difference in the time of ripening between plots unless the sulphur dioxide treatment had caused severe acute markings. In general, chlorosis due to sulphur dioxide is more difficult to detect or does not occur as readily on cereals as on alfalfa.

A type of marking, which probably should be classed as acute, occurs when only the epidermal cells on one side of the leaf are killed. Where this occurred the leaves became dull grey-green but did not lose their turgor.

Description of Markings on Alfalfa. In the case of alfalfa, careful comparison and study of a large collection of affected leaves and observations made on the plots at the time of treatment indicate that injuries are of two kinds, viz., acute and chlorotic. Whereas acute markings are the result of actual killing of cells, in chlorotic injury only the chlorophyll is affected. Depending on the severity of the injury and the location on the leaf, it is possible to subdivide acute markings in several types as follows: (a) marginal, (b) concentrated intercostal, (c) diffuse intercostal, and (d) veinal. It must be recognized, however, that these classes cannot be very definite, as the different types fade into one another, and it is often impossible to clearly separate them. With these limitations in mind they are useful in classifying and describing the numerous patterns of injury encountered.

The acute symptoms are, of course, the post-mortem appearance, as it were, of the affected leaf. The appearance of the leaf in the incipient injury stage is quite different. As soon as the initial breakdown has taken place the cells lose their capacity to retain the water in them. The cell sap permeates the intercellular spaces and gives the affected area a water-soaked appearance. This flaccid condition may be produced by agencies other than sulphur dioxide which are capable of causing a sudden breakdown in the tissue. The flaccid area dries out quickly under full sunlight or rather slowly in darkness or partial sunlight. In the initial stages of this drying-out process the affected portion of the leaf becomes dull grey-green. In a few days all signs of color disappear and the markings assume the familiar bleached appearance characteristic of sulphur dioxide injury.

It has been our experience that the acute marginal markings are the most likely to occur and are invariably found on plots with the other types present. Under conditions of high light intensity, and fairly high humidity, with concentrations above 0.50 p.p.m., practically all the markings may be of the acute marginal type. A series of hourly fumigations at different periods of the day was especially useful in indicating the various types of markings that may be caused by sulphur dioxide. In the early morning experiment, between 6.00 and 7.00 a.m., only a small number of acute markings occurred on a few fully expanded top leaves. From 7.30 to 8.30 a.m. and from 8.45 to 9.45 a.m. there



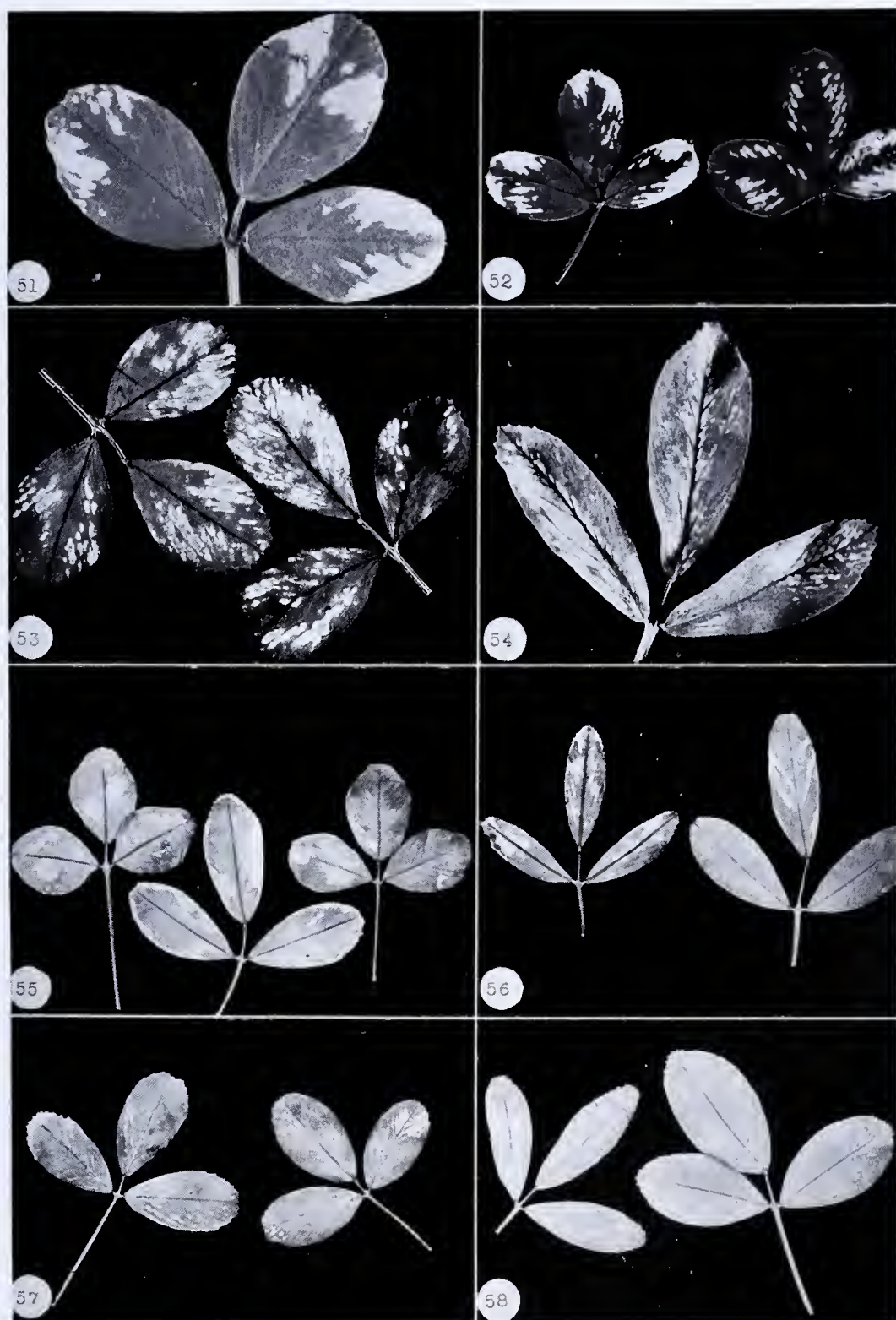
Acute marginal sulphur dioxide markings on alfalfa. FIG. 30. Slight marginal markings. FIG. 31. Acute markings from Plot C-17, treated with 0.37 p.p.m. sulphur dioxide for 383 hr., October 7-25, 1935. FIG. 32. Very severe markings (total injury). FIG. 33. Slight marginal markings. FIG. 34. Severe marginal markings. FIG. 35. Marginal markings. FIG. 36. Severe marginal markings. FIG. 37. Acute sulphur dioxide markings on Plot A-5, treated September 14 for one hour at 4.6 p.p.m. The markings merge from acute marginal to acute intercostal and chlorotic.



Various types of acute markings. FIG. 38. Acute marginal, intercostal and veinal sulphur dioxide markings. Plot D-8, July 10-11, seven hours at 1.4 p.p.m. FIG. 39. Acute sulphur dioxide markings; small, very young leaves. FIG. 40. Acute marginal and intercostal sulphur dioxide markings. The fully expanded leaves are more heavily injured than the very young leaves. Plot F-11, August 28, treated for one hour at 5.03 p.p.m. FIG. 41. Acute marginal and diffuse intercostal sulphur dioxide markings. Plot D-8 treated July 10-11 for seven hours at 1.4 p.p.m. FIG. 42. Acute sulphur dioxide markings. Plot D-2 treated August 30 for three hours at 1.32 p.p.m.*



FIG. 43. Acute basal sulphur dioxide markings. Plot F-6. September 28, 0.31 p.p.m. for 168 hr. followed by 0.92 p.p.m. for 37 hr. FIG. 44. Acute intercostal and basal sulphur dioxide markings. Plot I-3, treated with 4.60 p.p.m. sulphur dioxide 10.00-10.20 p.m. on September 24, and 4.40 p.p.m. sulphur dioxide 9.05-9.15 a.m. on September 25. FIGS. 45-50. These figures illustrate various types of acute intercostal markings.



FIGS. 51-52. Types of acute marginal markings merging into intercostal. FIG. 53. Acute intercostal markings with brown edges. Plot E-16, August 23 for one hour at 3.0 p.p.m. The brown stains appear as a result of high humidity or rain during treatment. FIG. 54. Diffuse intercostal and chlorotic sulphur dioxide markings. FIGS. 55-58. Various types of acute and diffuse intercostal sulphur dioxide markings.

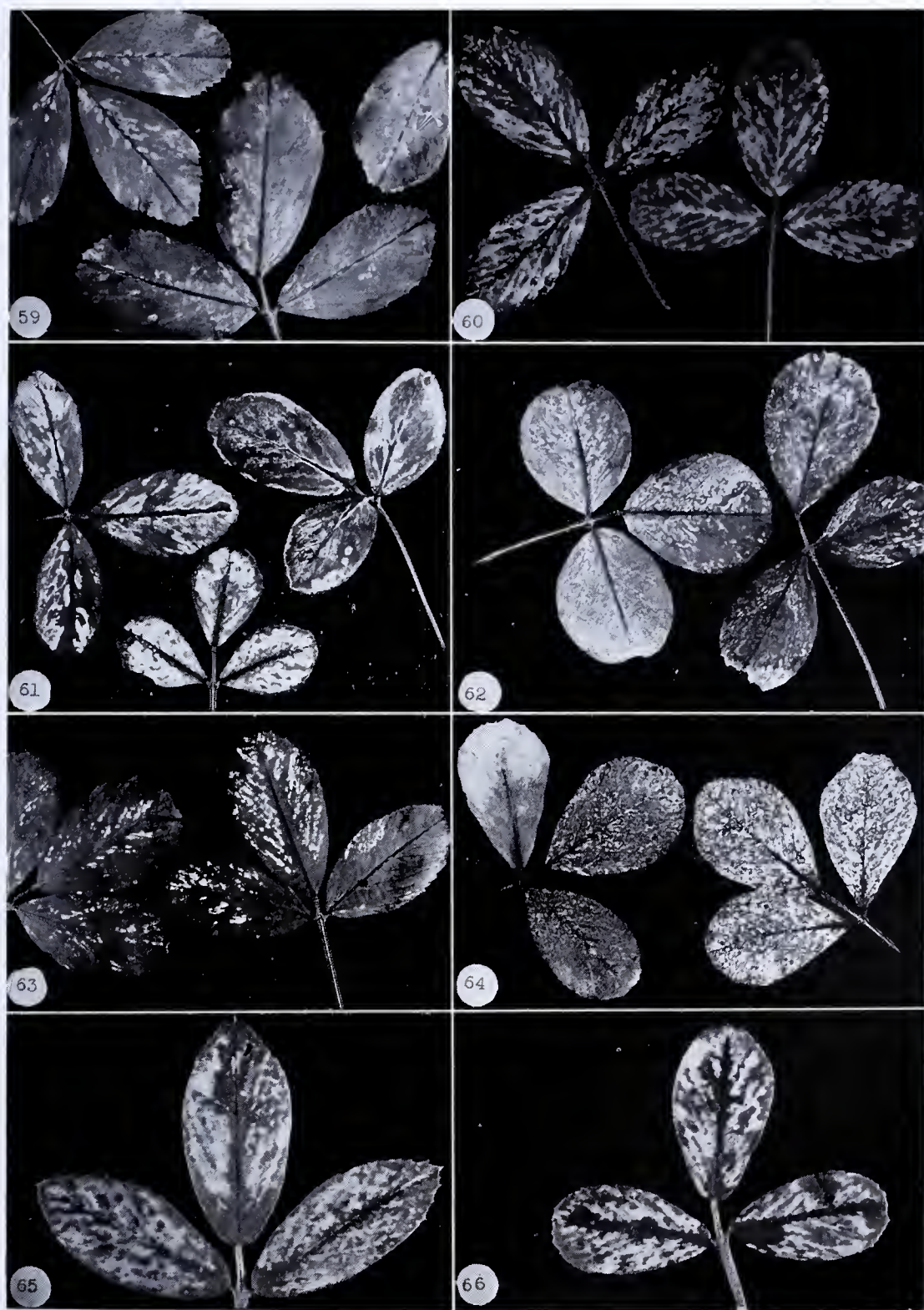


FIG. 59. Acute, spotted intercostal sulphur dioxide markings. Plot A-7, treated 2.93 p.p.m., 2½ hr., September 18. FIG. 60. Acute intercostal, almost veinal sulphur dioxide markings. Plot E-12, treated 3.18 p.p.m. for one hour, August 23. FIG. 61. Diffuse intercostal sulphur dioxide markings. Plot D-10, treated with 0.88 p.p.m. for 12 hr., August 17. Plot A-11, treated with 0.87 p.p.m. for 17 hr., August 2-3. FIG. 62. Diffuse intercostal sulphur dioxide markings. Plot D-11, October 3 and 4, 1.70 p.p.m. for one hour. FIG. 63. Acute intercostal sulphur dioxide markings covering small portions of the leaf surface. FIG. 64. Very fine, diffuse intercostal markings on lower leaves. Plot B-8, treated with 0.46 p.p.m. for 48 hr., July 29 to 31. FIGS. 65-66. Diffuse intercostal sulphur dioxide markings, involving most of the leaf surface.



FIG. 67. Diffuse intercostal sulphur dioxide markings, August 6. Plot B-10, treated August 1 with 0.50 p.p.m. for 10 hr. FIG. 68. Sub-marginal and diffuse intercostal sulphur dioxide markings. Plot A-11, treated with 1.42 p.p.m. for 3 hr., September 17. FIG. 69. Diffuse intercostal sulphur dioxide markings on upper epidermis; unmarked lower epidermis shown below. Plot D-11, treated with 1.70 p.p.m., for 40 min., October 4. FIG. 70. Diffuse intercostal sulphur dioxide markings. Plot A-11, treated with 0.87 p.p.m. for 17 hr., August 2-3. FIG. 71. Diffuse intercostal sulphur dioxide markings. Plot E-12, treated with 3.18 p.p.m. for one hour, August 23. FIGS. 72-75. Various types of diffuse intercostal sulphur dioxide markings. Note resemblance to potassium deficiency symptoms in FIG. 74.

were many diffuse intercostal, veinal and chlorotic markings on the shaded lower leaves. The acute marginal markings were more abundant on the upper leaves, where the light intensity was higher. After 10.30 a.m. until about 3.00 p.m. the symptoms were mostly acute marginal, markings appearing on all the leaves down the stem to the base of the plants. The floral parts of alfalfa are quite resistant to sulphur dioxide injury. However, on several occasions when concentrations above 1.00 p.p.m. were used acute markings were found on sepals and petals of the flowers. These markings occurred on the tip or sides and the sepals were more easily injured than the petals.

It is difficult to describe in detail the many types of acute marginal markings which occur on alfalfa. In Plates VII and VIII a few of those commonly found may be seen. Two leaves with very slight injury along the tip or margin of the leaf are shown in Fig. 30. This is the type of marking most often seen during low concentration experiments. More examples of acute marginal injury are shown in Figs. 31, 33 and 35. Frequently these markings occur on the sides of the leaf, as in Fig. 31, covering only a small part of the leaf area. Sometimes the entire margin of the leaf may be killed, as in Fig. 35. This type of injury merges into the severely injured type, such as is shown in Figs. 32, 34 and 36. Generally, in the latter type the region around the midrib remains green, but sometimes the chlorophyll on the entire leaf is decomposed. Such leaves usually curl up and subsequently drop off the plant. Almost invariably it is found that the young expanding leaves at the top of the plant are more resistant than the middle-aged fully expanded leaves. This is illustrated in Plate VIII, Figs. 40 and 42. Note the absence of injury on the newly expanded leaves, while there is severe injury on the leaves which are fully developed. Occasionally even very young leaves may show acute markings as in Fig. 39. In the acute marginal type of marking, as a general rule, the leaf is more often marked along the side at the centre or near the tip, but occasionally leaves are found with severe injury at the base, as in Plate IX, Figs. 43 and 44. This injury at the base may merge into the intercostal type, following the veins, so that the marking is in the centre of the leaf rather than on the edges.

The acute marginal and basal markings may merge gradually into the acute intercostal type. This is shown in Plate VII, Fig. 37, and Plate IX, Figs. 43 and 46. It is quite impossible to describe all the numerous types of concentrated intercostal markings. These may consist of small markings scattered over the leaf, as in Plate IX, Figs. 49 or 50, or they may cover almost the entire surface of the leaf, as in Figs. 45 and 46, or Plate X, Fig. 57. Sometimes the markings lie between the veins near the margin, as in Plate X, Fig. 52, or Plate XII, Fig. 74. This type of marking closely resembles the symptoms produced by potassium deficiency disease, and emphasizes the difficulties encountered by the field investigator in distinguishing between sulphur dioxide marks and those produced by other agencies. Occasionally acute intercostal markings may arise which in the field might easily be confused with various leaf spots. It was

noticed that after periods of rain or very high humidity, when marking occurred, a definite brown ring appeared at the edge of the killed area, Plate X. Fig. 53. The acute intercostal type of marking merges, in some cases, almost imperceptibly into the veinal type. In Plate XI, Figs. 60 and 63, the markings appear to follow the veins, and in many cases they occupy the entire space between the smaller veins. These are classified as acute intercostal rather than veinal, because the pattern is not as definite as shown in the case of true veinal markings.

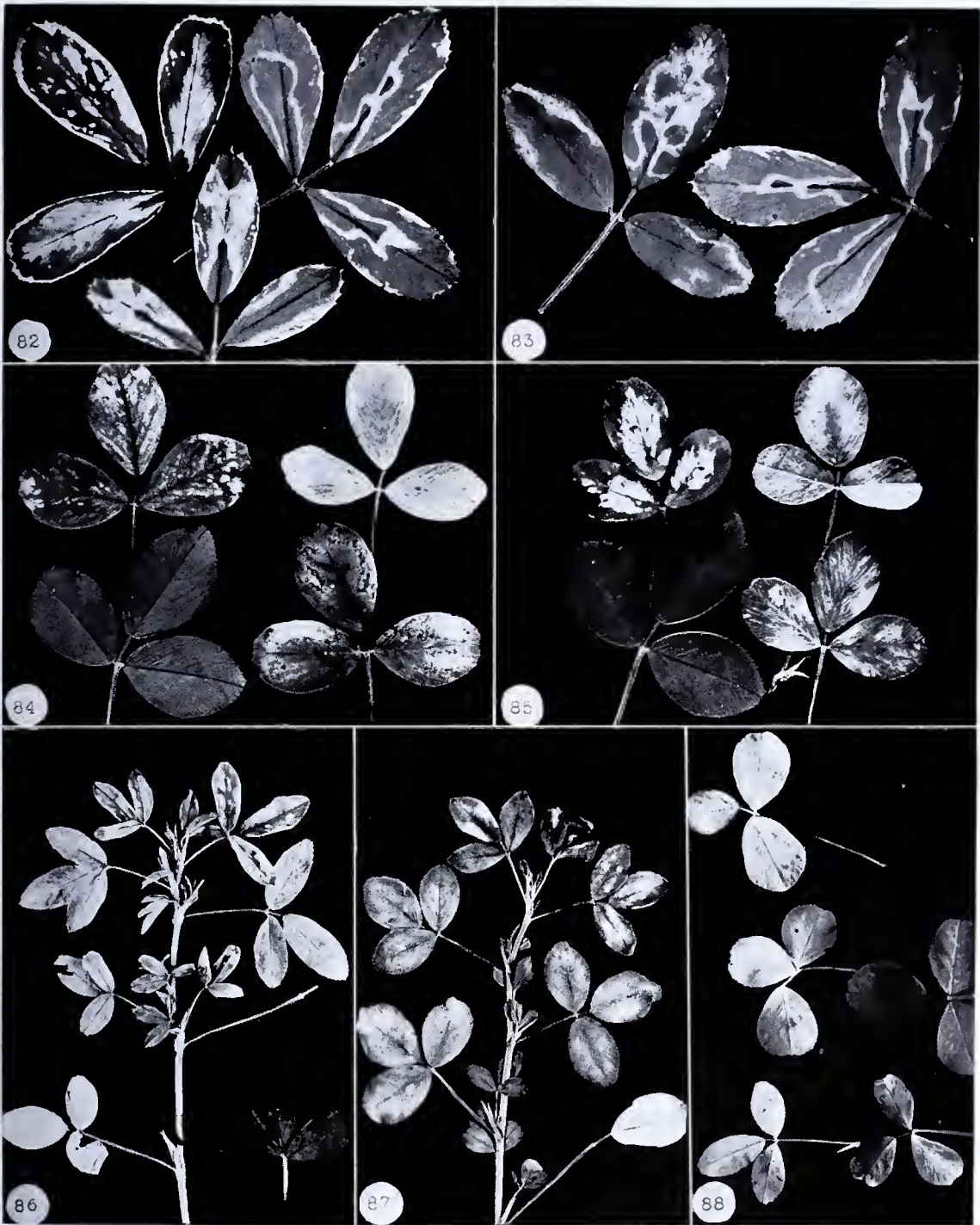
Diffuse intercostal markings differ from the acute type of intercostal marking in that the edges of the injured area are not sharply delimited, and very often practically the entire surface of the leaf is lacking in chlorophyll. Some types of diffuse markings may be seen in Plate XII, Figs. 67, 68, 69, 70, 71, 72, 73 and 75. While the acute intercostal markings are visible on either side of the leaf, quite often the diffuse type affects only one epidermis. For instance, in leaves shown in Fig. 69 of Plate XII the markings occur on the upper epidermis only, the lower epidermis being entirely free from injury. As a general rule in the diffuse intercostal types of marking, the midrib is quite free from injury. Diffuse intercostal markings are more often found on the lower shaded leaves, and they occur usually under conditions of low light intensity and high humidity.

Veinal markings are really a type of diffuse intercostal markings, but since they make a definite pattern following the veins of the leaf, it seems better to classify them separately. Veinal markings do not occur as frequently as the other types mentioned, but sometimes under conditions of low light intensity sulphur dioxide markings may follow the veins. Occasionally this may occur on the growing top leaves, as in Plate XIII, Fig. 80, although generally the older leaves only are affected. Various veinal markings are shown in Plate XIII, Figs. 76, 77, 78, 79 and 81. It should be noted that in most cases these markings do not follow the midrib of the leaf. An exception to this may be noted in Fig. 79, where the marking has followed the midrib and branched out on the smaller veins to the side.

Chlorotic symptoms of sulphur dioxide injury are the result of the breakdown of the chlorophyll in the leaf. The leaf tissue is not necessarily killed but may function at a reduced rate. Chlorosis caused by sulphur dioxide may be of two types, either transient or permanent. In the transient form, single plants or a whole plot may show some loss of the normal green color, which returns to normal within a few days. This transient chlorosis may be so slight as to be readily overlooked, except where control plants are at hand for direct comparison. The permanent type of chlorosis consists of a definite loss of chlorophyll, so that the leaf presents a yellow, yellowish-green, or brown appearance. Oftentimes this type of chlorosis and acute injury are intermingled on the same leaf. Although there is no actual killing of tissue in the chlorotic leaves they are really similar to old leaves after this change has taken place. It is impossible to distinguish between leaves of this type and normal senescent leaves of the



Various types of veinal sulphur dioxide markings on alfalfa leaves. FIG. 76. Plot D-11, treated 1.75 p.p.m. for 20 min., October 3. FIG. 77. Plot D-16, treated with 1.15 p.p.m. for 5¼ hr., July 9. FIG. 78. Plot B-10, treated with 0.50 p.p.m. for 10 hr., August 1. FIG. 79. Plot F-11, treated with 5.03 p.p.m. for one hour, August 28. FIG. 80. Veinal markings on the terminal leaves. Plot F-11, treated the same as in FIG. 79. FIG. 81. Veinal and diffuse intercostal sulphur dioxide markings. Treatment the same as in FIG. 77.



Leaves showing chlorosis as a result of sulphur dioxide treatment. FIG. 82. Acute intercostal, acute marginal and chlorotic markings, Plot A-5, treated with approximately 4.8 p.p.m. for one hour on September 14. FIG. 83. Acute intercostal and chlorotic sulphur dioxide markings, Plot A-5 (see FIG. 82 for sulphur dioxide treatment). FIG. 84. Chlorotic and normal leaves. Plot C-17, treated October 7-25, for 383 hr., with average concentration of 0.37 p.p.m. Normal leaf from cabinet control Plot D-16. FIG. 85. Chlorotic, acute intercostal and normal leaves. Same treatment as in FIG. 84. FIG. 86. Chlorotic leaves from Plot C-17; one normal leaf from Plot D-16. (Treatment as in FIG. 85). FIG. 87. Chlorotic and acute sulphur dioxide markings, leaves from Plot C-17. (Treatment as in FIG. 85). FIG. 88. Chlorotic and normal leaves, not treated, from control Plot D-16.



FIG. 89. Untreated chlorotic and normal leaves, from plants under cabinet for 383 hr. Plot D-16. FIG. 90. Two chlorotic leaves, on left, taken from treated Plot C-17. Leaves on right, one chlorotic and the other normal, taken from cabinet control Plot D-16. FIG. 91. Albino alfalfa, showing chlorophyll deficiency on portions of leaves. FIG. 92. Leaf spot caused by *Pseudopeziza medicaginis*, Summerland Experimental Farm. FIG. 93. Yellow markings on alfalfa leaves from plots, August 23. Not caused by sulphur dioxide. FIG. 94. Yellow markings on alfalfa from Experimental Farm field near plots, October 23. FIGS. 95-96. Tipburn or insect injury, Summerland Experimental Farm field near plots.



Various types of markings on alfalfa leaves not caused by sulphur dioxide. FIG. 97. White, intercostal markings from Plot D-19, July 15. FIG. 98. White markings on alfalfa, control Plot B-5 (corner plant). The leaves on the same plant were affected in successive crops. FIGS. 99-100. Finely speckled type of white-spot markings, Plot F-22, August 31. FIG. 101. Typical white-spot from Plots A-3 (fumigated) and A-4 (control). FIG. 102. Soft white-spot from an Experimental Farm field. FIG. 103. Possibly white-spot lesions ringed with brown edge. FIG. 104. White, intercostal markings, brown edge, possibly a type of white-spot.

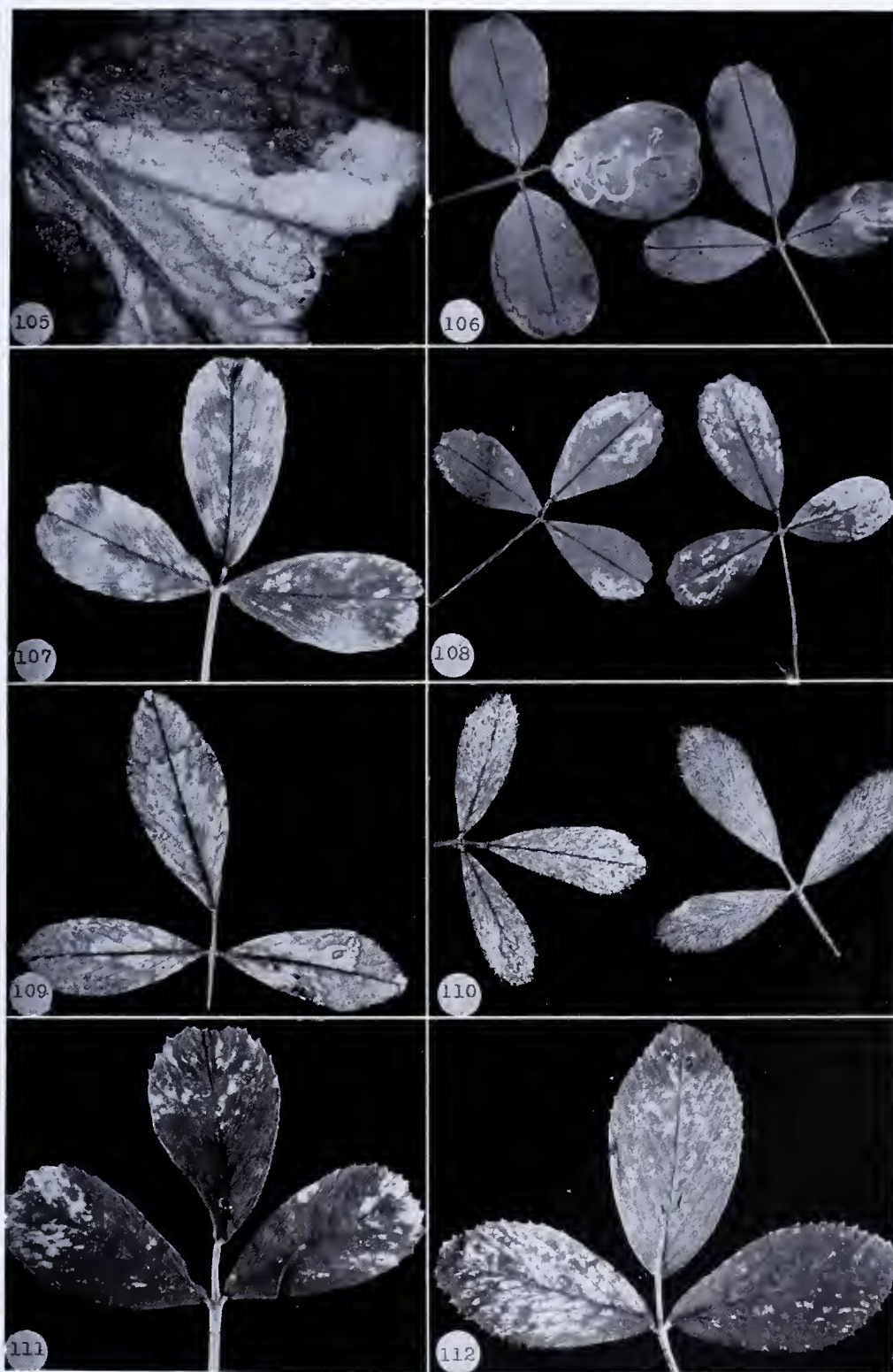


FIG. 105. Enlarged view of leaf miner (*Agromyza* sp.) from Plot D-7, October 2. FIG. 106. Leaf miner (*Agromyza* sp.) from Plots F-17 and D-7, October 2. FIG. 107. Diffuse, white, intercostal lesions, resembling sulphur dioxide markings, from the Experimental Farm field near the plots. FIG. 108. Insect marks, possibly aphids, leaves from the experimental plots. FIGS. 109-110. Fine, grey marks on one side of alfalfa leaf (like early sulphur dioxide symptoms), Experimental Farm field near plots, August 23. Possibly chlorophyll break-down in epidermal cells. FIG. 111. Diffuse, white, intercostal lesions resembling certain types of sulphur dioxide marking. Collected on Plot D-18 (control). FIG. 112. Diffuse, white intercostal lesions on alfalfa from Experimental Farm field near plots, August 23.



FIG. 113. Young barley 26 days old. This indicates the effect of fumigation with 1.2 p.p.m. of sulphur dioxide for 3 hr., 25 min. at 70% relative humidity.



FIG. 114. *Sulphur dioxide markings on leaves, stems and awns of barley, treated with 2.00 p.p.m. for 21 hr., 40 min., when plants were 37 days old.*



FIG. 115. *Sulphur dioxide markings on leaves, stems and awns of barley.*

control plot unless the injured leaves appear among the upper middle-aged leaves, which are normally green on a healthy plant.

It appears that chlorosis caused by sulphur dioxide may arise in two different ways. Thus chlorosis may result from a very short severe sulphur dioxide treatment, and invariably this type is associated with acute markings on the plant. The other type of chlorosis develops very slowly and is the result of an accumulation of sulphate in the leaf beyond the point of tolerance. When this point is reached a gradual breakdown of the chlorophyll follows and the leaves become prematurely old. This type of chlorosis was found in long continued experiments where treatments with very low concentrations of sulphur dioxide of the order of 0.10 to 0.30 p.p.m. were applied. Periods of high humidity seemed to increase the amount of chlorosis. Usually in such experiments about the time the first chlorotic symptoms became apparent a few leaves showed very light acute marginal symptoms of injury. These symptoms did not increase with further gas treatment but the chlorosis became more pronounced the longer the treatment after this point.

It is difficult to illustrate adequately types of chlorotic marking with black and white photographs. However, in Plate XIV, some of these types are shown in comparison with normal leaves. For instance, Figs. 82 and 83 show leaves which are partly chlorotic, other types of acute markings also being present. In these figures the chlorosis has followed the central midrib and the acute marking is on the margin. Generally, the chlorosis affects the entire surface of the leaf. This is shown in Figs. 84, 85, 86 and 87. Some of the best examples of chlorotic markings on leaves were found in a plot treated with a concentration of 0.37 p.p.m. of sulphur dioxide for 383 hours in October. At the close of this fumigation a considerable number of chlorotic leaves were present on the treated plot. In some cases all leaves on a leader were chlorotic, as in Figs. 86 and 87. Undoubtedly some of the chlorotic leaves in the treated plot became chlorotic from causes other than sulphur dioxide, because chlorotic leaves were also present, but in smaller number, in the control plot. It is quite impossible to differentiate between ordinary chlorotic leaves and those which become chlorotic from the effects of sulphur dioxide. This is illustrated in Fig. 88 where chlorotic leaves from the control plot are indistinguishable from leaves that had received sulphur dioxide treatment. In Fig. 90 the two leaves on the left were from the treated Plot C-17 while those on the right, one chlorotic and one normal, were from the control plot.

Effect of Sulphur Dioxide on the Internal Structure of Alfalfa Leaves

In addition to making observations on the external visible symptoms of sulphur dioxide injury on alfalfa leaves, it was thought that a study of the effects of the gas on the cells of leaves would be valuable. Considerable preliminary work was necessary to determine the best method of preserving the leaf tissues. After testing four different fixatives it was found that those containing

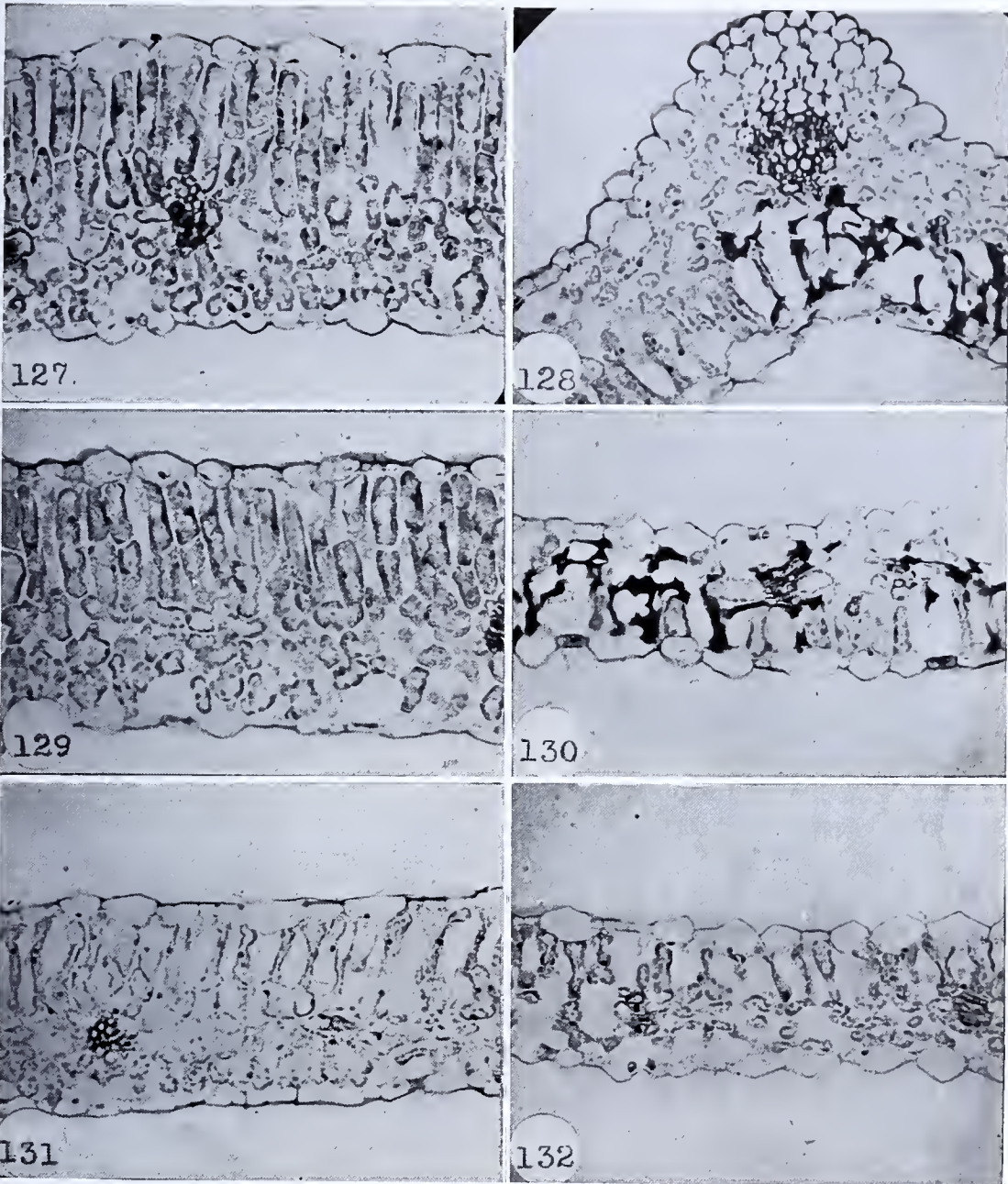
formalin gave the most satisfactory results and a formalin-alcohol mixture was, therefore, used. During and after sulphur dioxide treatments small sections were cut out of leaves and dropped into the fixative. After washing, dehydrating and embedding in paraffin, sections were cut 10 to 15 microns in thickness with a microtome. Sections from a treated plot, along with its control plot, were mounted in rows on the same slide and thus received identical staining with safranin-gentian-violet.

The Anatomy of a Normal Alfalfa Leaf. Transverse sections of normal alfalfa leaves from Plot E-11 are shown in Plate XXI, Figs. 127 and 129, and from Plot C-12 in Plate XXIV, Figs. 147, 149, 151 and 153. On both upper and lower epidermis is a thin layer of waxy cuticle, which is more pronounced on the upper side of the leaf. There is little difference in the single layer of cells which comprise the epidermis on either side of the leaf. Transverse sections through these cells show little detail, but they can be readily studied in plane sections. Directly below the upper epidermis lie two closely packed rows of palisade cells. Beneath each stomata there is a small chamber or air space, otherwise the cells lie in regular rows, closely appressed. In a plane section through this part of the leaf the cells appear as round discs with a hollow centre, except where the nucleus is present and occupies part of this space. (Figs. 139 and 141.) The dense protoplasm around the walls of the cell in either transverse or plane view is composed mainly of chloroplasts. In transverse section the nucleus lies in the centre, or towards one side of the cell, and usually there is a large vacuole present.

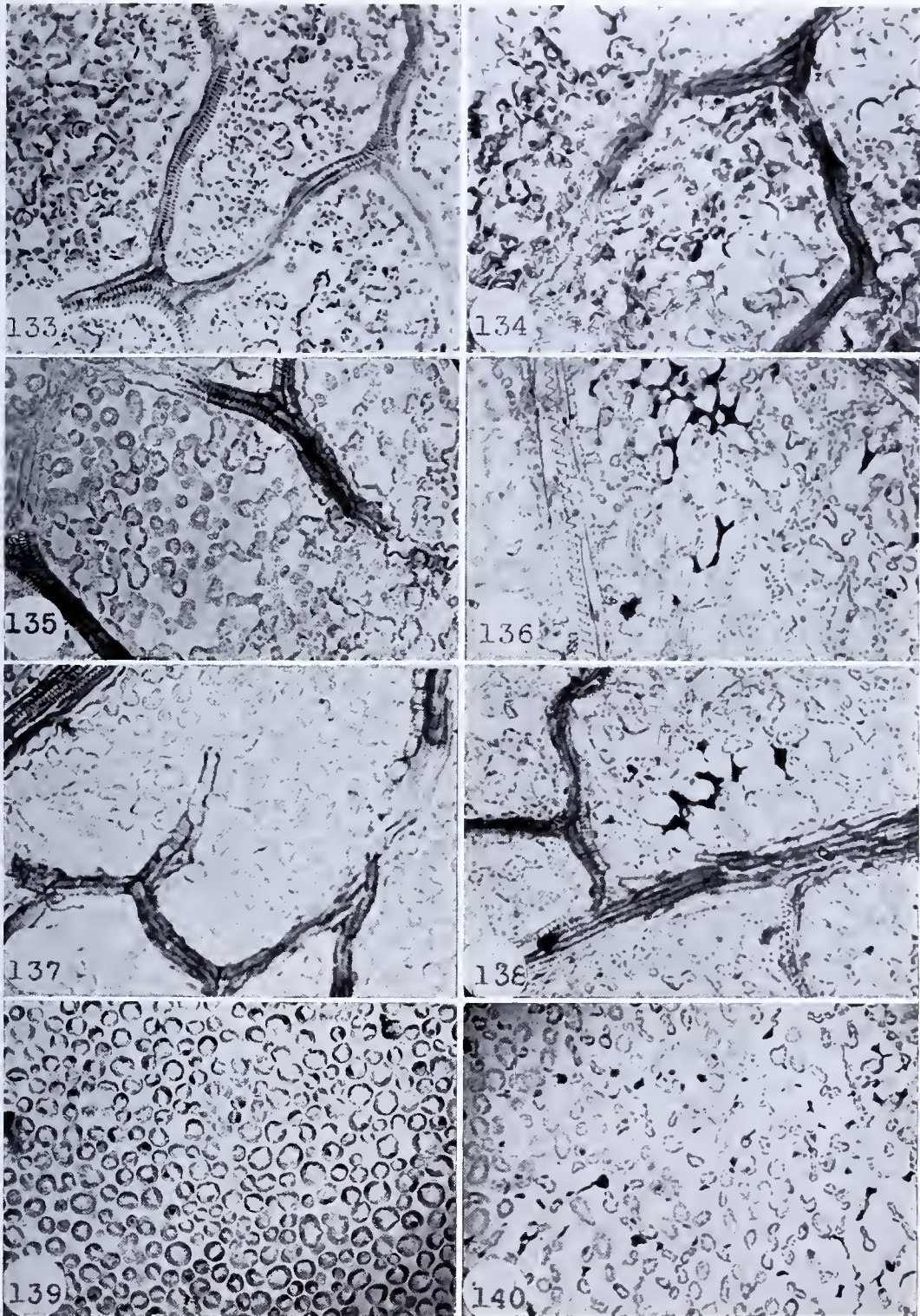
The mesophyll layer, composed of loosely connected, irregular shaped cells, lies between the palisade layer and the lower epidermis. There are large air spaces between the cells in this area. Chloroplasts are present though not as numerous as in the palisade layer.

Changes in Anatomy Caused by Sulphur Dioxide. Safranin shows great affinity for dead tissues, hence it was easy to recognize the killing effect of sulphur dioxide by the dense staining reaction of this dye. In general, unless dead cells were present, sections from fumigated leaves did not stain as heavily as those from control leaves. It was possible to differentiate between treated and control leaves on this staining reaction alone. Whether high or low sulphur dioxide concentrations had been applied it was possible to detect slight differences in the cells between control and treated specimens.

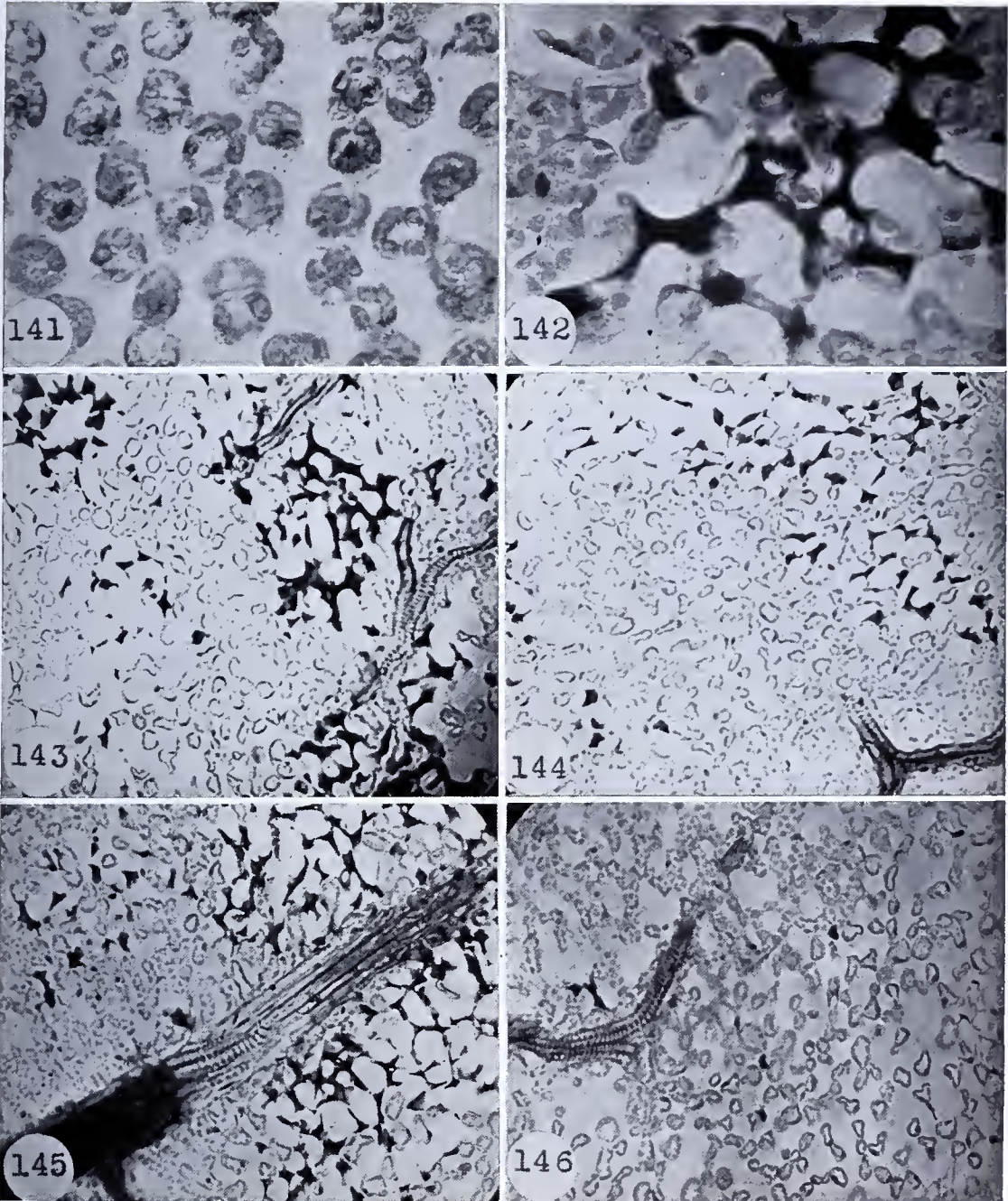
The Effect of High Concentrations. With the exception of Figs. 133 and 134 in Plate XXII, all figures of control and treated alfalfa from Plots E-11 and E-12 show the condition of the leaves 10 days after treatment. The sulphur dioxide treatment of Plot E-12 consisted of 3.00 p.p.m. for 40 min. and resulted in a considerable amount of injury. Marked shrinkage of tissue occurred in the injured leaves and even those with no external symptoms of injury showed internal shrinkage, particularly in the palisade cells, 10 days after treatment



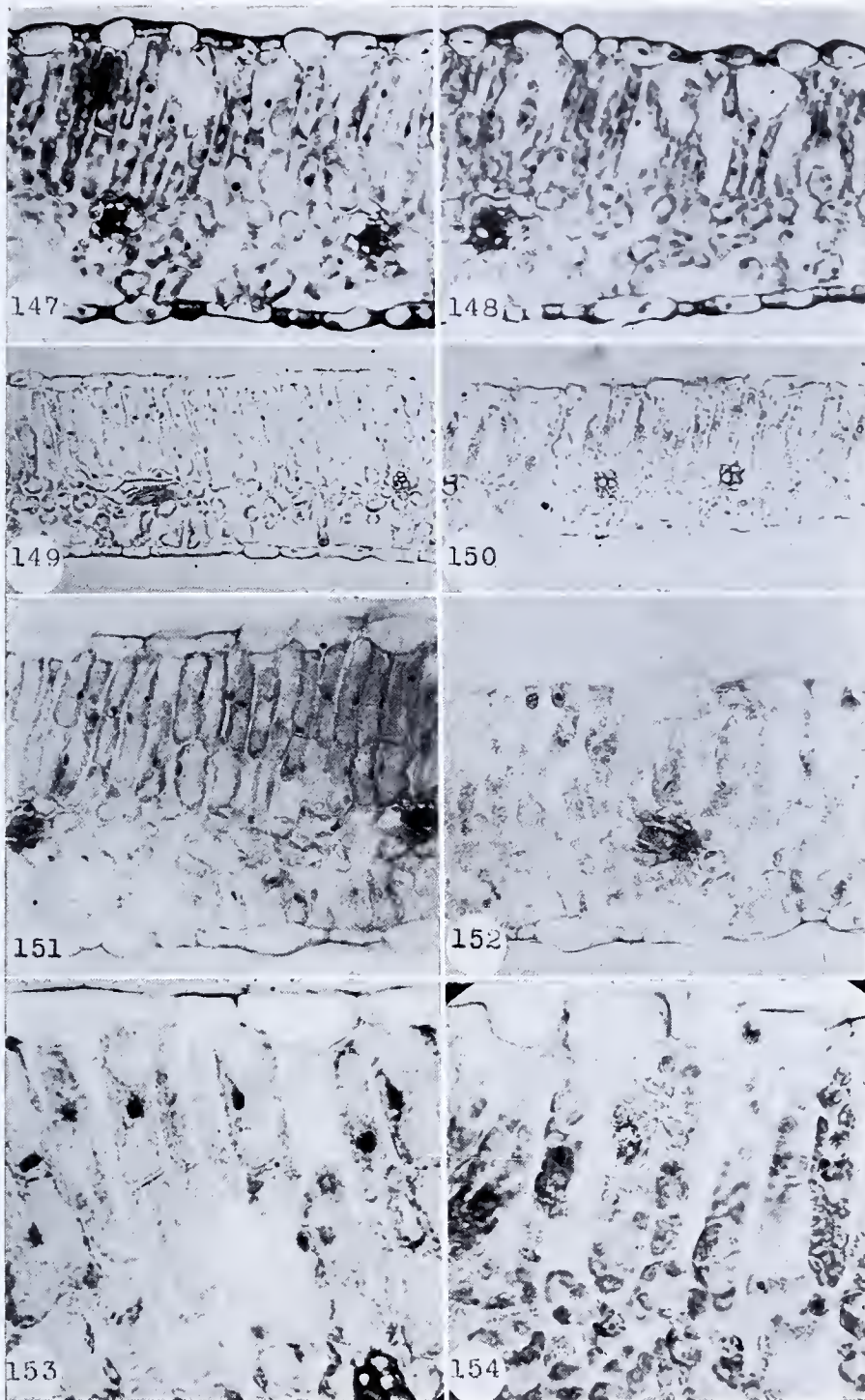
Transverse sections of alfalfa leaves from Plot E-12, treated with 3.00 p.p.m. sulphur dioxide for 40 min., 8.00 to 8.40 a.m. on September 4, 1935, and from control Plot E-11. All leaves fixed in formalin-alcohol or B.C. fixative. Sectioned 10 microns in thickness, stained with safranin and gentian-violet. FIG. 127. Normal leaf from Plot E-11. Magnification $\times 200$. FIG. 128. Leaf showing veinal injury from Plot E-12. Magnification $\times 200$. FIG. 129. Normal leaf from Plot E-11. Magnification $\times 200$. FIG. 130. Severely injured leaf from E-12. Note great shrinkage of leaf. Magnification $\times 200$. FIG. 131. Leaf from Plot E-12, showing shrinkage of cells as a result of sulphur dioxide treatment. Magnification $\times 200$. FIG. 132. Leaf from Plot E-12, showing effects of sulphur dioxide on cells. Magnification $\times 200$.



Plane sections through leaves from Plots E-12 and E-11, treated as in Plate XXI. FIG. 133. Normal alfalfa from Plot E-11, showing mesophyll cells between the veins. Magnification $\times 233$. FIG. 134. Alfalfa leaf from Plot E-12, first symptoms of injury just appearing. Note shrinkage and breakdown of cells. Magnification $\times 233$. FIG. 135. Normal alfalfa leaf from Plot E-11. Section through palisade and mesophyll cells. Magnification $\times 200$. FIG. 136. Plot E-12. Showing killed mesophyll cells near the veins. Note shrinkage in nearby cells. Magnification $\times 200$. FIG. 137. Plot E-11, normal alfalfa leaf, section through mesophyll and palisade cells. Magnification $\times 200$. FIG. 138. Plot E-12, slightly injured leaf, few dead mesophyll cells. Magnification $\times 200$. FIG. 139. Plot E-11, normal palisade cells. Magnification $\times 200$. FIG. 140. Plot E-12. Injured and killed palisade cells. Magnification $\times 200$.



Plane sections of alfalfa leaves from Plot E-12, treated with 3.00 p.p.m. sulphur dioxide for 40 min., September 4, 1935, and control Plot E-11. The leaves were fixed in formalin-alcohol or B.C. fixative. Sectioned 10 microns in thickness, stained with safranin and gentian-violet. FIG. 141. Normal alfalfa leaf. Plot E-11. Section through palisade cells. Magnification $\times 600$. FIG. 142. Severely injured leaf showing dead mesophyll cells. Magnification $\times 600$. FIG. 143. Section through mesophyll cells of injured leaf. Plot E-12. Many cells dead or shrunk. Magnification $\times 200$. FIG. 144. Section through injured mesophyll and palisade cells. Plot E-12. Magnification $\times 200$. FIG. 145. Section through leaf showing veinal injury. Plot E-12. Magnification $\times 200$. FIG. 146. Section through palisade and mesophyll cells, leaf very lightly injured. Few dead cells and much shrinkage. Plot E-12.



Transverse sections through alfalfa leaves from Plot C-11 at close of 504 hr. fumigation at 0.10 p.p.m. August 14 to September 4, and control Plot C-12. Leaves were fixed with B.C. fixative. Sectioned 10 microns in thickness and stained with safranin and gentian-violet. FIG. 147. Plot C-12. Transverse section of normal green leaf. Magnification $\times 300$. FIG. 148. Plot C-11. Transverse section of fumigated green leaf. Magnification $\times 300$. FIG. 149. Plot C-12. Transverse section of normal green leaf. Magnification $\times 200$. FIG. 150. Plot C-11. Transverse section of treated leaf. Cell contents show some coagulation of protoplasm and slight shrinkage. Magnification $\times 200$. FIG. 151. Plot C-12. Transverse section of normal leaf. Magnification $\times 300$. FIG. 152. Plot C-11. Transverse section of green leaf. Cells show some shrinkage and coagulation of contents. Magnification $\times 300$. FIG. 153. Plot C-12. Palisade cells of normal green leaf. Magnification $\times 700$. FIG. 154. Plot C-11. Palisade cells of green leaf showing some coagulation of cell contents. Magnification $\times 700$.

with sulphur dioxide. (Compare Figs. 131 or 132, Plate XXI, with Figs. 127 or 129.) There are no dead cells present in these leaf sections, but the whole leaf has shrunk in thickness and effects of treatment may be seen on both palisade and mesophyll cells. Sections through parts of the leaf where cells were actually killed are shown in Figs. 128 and 130. The cells which were not killed show a similar shrinkage. (Figs. 131 and 132.) In the section of the leaf shown in Fig. 128 the marking was veinal, extending along the upper surface of the midrib. All the cells from the epidermis to the vascular bundle were killed in this leaf. Injuries to cells in the palisade and mesophyll layers of the leaf are shown in plane sections in Plate XXII, Figs. 134, 136, 138, 140, and Plate XXIII, Figs. 142, 143, 144, 145 and 146. The degree of injury varies from the killing of a few cells only in the mesophyll layer, as in Fig. 138 or 146, or in the palisade layer, as in Fig. 140, to the total killing of large masses of cells in both layers of the leaf, as in Figs. 143, 144 and 145. It should be noted that closely adjacent to areas where many cells are killed those surviving appear to be about the same as cells in the leaves which show no external symptoms of injury. This treatment with 3.00 p.p.m. of sulphur dioxide has caused some internal shrinkage even in the cells of unmarked leaves. Possibly this may be related to the loss of moisture as there is some decrease in green weight of a plot after such a treatment.

The Effect of Low Concentrations of Long Duration. Plot C-11 was treated continuously from 4.40 p.m., August 14, to 3.40 p.m., September 4, a period of 504 hr., at an average sulphur dioxide concentration of 0.09 p.p.m. At the same time control plot C-12 was subjected to a similar environment under a cabinet but was supplied with sulphur-dioxide-free air. There were no symptoms of sulphur dioxide injury present on the plants in C-11, although a number of chlorotic leaves were noted. To the eye this chlorosis was not more marked in C-11 than in C-12, although analysis of chlorophyll content indicated a slight decrease in leaves from Plot C-11.

Green, fully expanded leaves were fixed from plants in both plots, also lower chlorotic leaves. Transverse sections of green leaves at various magnifications from both plots are shown in Plate XXIV. There are no clear differences between the different plots, as in the case of E-12 and E-11. However, it was possible in all cases to pick out the leaf sections which came from the fumigated plot. Sections from some leaves showed very little difference. (Compare Fig. 147 (Plot C-12) with Fig. 148 (Plot C-11).) In other leaves slight shrinkage seems to have occurred, both in thickness of leaf and in individual cells. The cell outlines are not as distinct in some leaves from Plot C-11, and there seems to have occurred either a slight coagulation of the cell protoplasm or a breakdown of some of the chloroplasts. This difference in individual cells may be seen by comparing Fig. 153 (Plot C-12) with Fig. 154 (Plot C-11). In none of these leaves was there found any indication of dead cells. Although proof of the functional activity of the leaves of the fumigated plot as a whole was

furnished by data on carbon dioxide exchange, it is interesting that one could say without hesitation which leaves had been subjected to sulphur dioxide. This indicates that stained leaf sections might well be of value in delimiting disputed zones of sulphur dioxide occurrence.

The lower chlorotic leaves from both plots were very similar in appearance. Whether taken from the treated plot or control plot there was great shrinkage of cell contents, chloroplasts were lacking, and there were large air spaces throughout the leaves. No dead cells were present in any of the sections examined. The stomata on these chlorotic leaves picked from both plots were open and no difference could be detected in this respect between fumigated and control leaves.

Discolorations on Crops not Caused by Sulphur Dioxide

In the study of sulphur dioxide symptoms in the field, many types of discolorations and disease symptoms may be found on various plants which closely resemble markings caused by sulphur dioxide. A few of the more important of these symptoms on cereals and alfalfa should, perhaps, be mentioned.

Young cereals in the early spring are sometimes affected by frost, and the resulting symptoms are very similar to sulphur dioxide markings. Richards (11) has described a type of frost banding which might well be confused with sulphur dioxide markings. The affected plants show three different types of lesions. The first, and probably the most common, is an effect on the chlorophyll. A yellow chlorotic band appears on the leaf, sometimes several, separated by areas of normal green tissue. In this type of injury the cells apparently remain alive and active. In the second type there is some killing of the cells. The tissues of barley and wheat become white. In oats and occasionally in wheat the affected areas turn a reddish color. In this type of injury the vascular tissue remains alive, and above and below the killed areas the leaf continues to function. The third type of injury is the most severe. It consists of a complete collapse of the tissues at the soil line. Injured plants usually bend over at the point of injury and the symptoms are very similar to damping-off caused by certain fungi.

Periods of very hot, dry weather during the early growth of cereals often cause tipburn, which is identical with sulphur dioxide markings on the tips of the leaf. The affected areas are bleached white and may extend from one-eighth to one-half inch down from the tip of the blade. Drought and heat injury are of frequent occurrence on cereals later in the summer and cause premature yellowing and desiccation, especially of the lower leaves. This basal leaf discoloration is of common occurrence in cereals almost wherever these are grown. It is usually most severe in unfavorable soils or where the environmental conditions are adverse. The lower leaves of affected plants become chlorotic in the case of wheat and barley, but in oats they usually are of reddish color. It is,

of course, possible to obtain chlorosis on lower leaves through the action of sulphur dioxide, but, in the absence of acute markings on the upper green leaves and also old, acute markings on the lower leaves, it is usually unsafe to attempt to separate chlorotic sulphur dioxide markings from basal leaf discoloration.

In alfalfa, especially in the first crop, small dead shoots are sometimes found. These are an effect of weather injury and occur wherever alfalfa is grown. The symptoms are quite different from injury caused by sulphur dioxide. Often the tips of certain leaves become bleached white in alfalfa, especially where they touch some object and are burnt by heat. Some of these tipburn markings are very similar to acute sulphur dioxide injury.

It is usually quite easy to distinguish between symptoms of the various fungous or bacterial diseases of alfalfa and sulphur dioxide injury. Two very common leaf spots, *Pseudopeziza medicaginis* and *Pyrenopeziza medicaginis*, were quite prevalent on alfalfa in the smoke zone near Trail, and occurred occasionally on the plots at Summerland. No difficulty was found in distinguishing between the symptoms produced by these and sulphur dioxide injury.

Various insects, such as aphids, red spiders, and leafhoppers, cause certain types of markings or chlorotic discolorations on the leaves, but these can usually be distinguished from sulphur dioxide markings. In general, it may be said that there is little danger of confusing sulphur dioxide injuries with those produced by fungi or insects on alfalfa. The same is not true, however, of various physiological disorders which may arise in alfalfa of which our knowledge is very incomplete. Both in the field surveys and on some of the plots at Summerland white spot markings, such as those described by Richards (12) have been found. (Plate XVI, Fig. 101.) Usually there is little difficulty in distinguishing white spot from sulphur dioxide markings, but where the white spot symptoms are in abundance certain leaves may be found with marginal lesions which are identical to those produced by sulphur dioxide. Leaf specimens which show white spot lesions, ringed with brown stains, which closely resemble certain markings caused by sulphur dioxide, are shown in Figs. 103 and 104 of Plate XVI.

A common type of intercostal marking, which has been called soft white spot to distinguish it from the true white spot disease, is shown in Fig. 102, Plate XVI. The symptoms are usually clear-cut and sufficiently different from those of sulphur dioxide to be readily differentiated. However, occasional leaves were found which closely resembled intercostal sulphur dioxide markings. (Plate XVI, Figs. 97 and 98, and Plate XVII, Figs. 107, 111 and 112.) The leaf shown in Fig. 98 was collected from a plant on one of the experimental plots. This plant was affected for three successive crops by the same type of white spots, the cause of which was not known. On another plot a single plant was affected by a brownish white, pin-point, speckled marking on several crops in

succession, as shown in Plate XVI, Figs. 99 and 100. In the field surveys there was a type of grey, streaked, intercostal marking found which usually appeared only on the upper epidermis, but occasionally on both sides of the leaf. It has not been possible to determine the cause of this breakdown of chlorophyll, but the disease although of minor importance was of wide-spread occurrence in British Columbia and Washington. The symptoms are identical with certain types of diffuse intercostal markings caused by sulphur dioxide. (Plate XVII, Figs. 109 and 110.) The close similarity of these to sulphur dioxide marking may be seen by comparing these figures with those shown in Plate XII, Figs. 70 and 72.

A type of marking consisting of yellow bands or stripes across alfalfa leaves, such as shown in Figs. 93 and 94 of Plate XV, was often found in the plots at Summerland, especially late in the summer. These leaves appeared perfectly normal except for these bright yellow discolorations. In field surveys similar markings were found and some of them were probably due to a virus disease.

On the plots at Summerland occasional plants of a semi-albino type appeared, the discolored leaves being present on successive crops. Possibly some genetic factor is responsible for this type of leaf. A part of a stem with several leaves is shown in Plate XV, Fig. 91. Affected areas are yellowish-white in color, but otherwise the plant developed normally and seemed quite healthy.

In the smoke area one of the commonest discolorations on alfalfa was caused by a disease known as yellow top. This disease was characterized by a distinct yellowing of the leaves and, in severe cases, a stunting and thickening of both stems and leaves. Prior to flowering time the buds were killed and the plants ceased growing. The disease was usually most severe on dry fields, seldom occurring on fields which were well irrigated. It has been found that it is due to deficiency of boron in the soil, associated with unfavorable soil moisture conditions.

Symptoms of Sulphur Dioxide Injury on Garden Plants

Most of the common fruit trees, such as apple, pear, peach, plum and cherry, are fairly resistant to injury from sulphur dioxide. On several occasions markings were found on apple foliage. The type of marking is shown in Plate V, Fig. 15. Usually markings are marginal, extending down between the veins; occasionally all markings may be intercostal. The color is a bright brown which becomes duller with age. It is sometimes difficult to distinguish between sulphur dioxide markings and those due to natural senescence of the leaves. Leaves on sucker shoots frequently begin to dry up and appear very much as though they had been injured by sulphur dioxide.

On one occasion quite severe injury was found on grapes. Most of these markings were in the form of small intercostal spots scattered over the surface

of the leaf. (Plate V, Fig. 18.) The color, shortly after the leaf was injured, was a deep reddish-brown.

In raspberries a narrow rim on the margin of the leaf was usually affected, and projections of this injury followed down between the veins toward the midrib. (Plate V, Fig. 17.)

Although markings on a great variety of vegetables have been noted, particularly in the vicinity of Trail and occasionally in gardens not more than 20 miles distant, it is possible to illustrate only a few of these. Characteristic symptoms on tomato, carrot, squash and potato are shown in Plate VI, tomato, Fig. 24, and potato, Fig. 28. The injuries were usually intercostal and, in potato, were frequently surrounded by a dark band between the killed and the living tissue. Usually these markings were an ivory color and turned light brown with age. In squash, Fig. 27, the markings were marginal and intercostal and remained a greyish-white color. Carrot was almost invariably marked on the tips of the small leaflets. The color was white at first, turning brown with age.

Of the flowers, the markings on columbine were a clear white and mostly on the margin of the leaf. Sometimes a purplish band was present at the junction between living and killed tissue. (Plate V, Fig. 21.) Hollyhock was marked quite severely on several occasions, and very definite irregular intercostal spots seemed to be characteristic of this species. On bleaching out after injury these spots remained almost white and did not have a tendency to color with age. (Plate VI, Fig. 26.) Zinnias were marked mostly on the edge of the leaf with killed areas extending down between the veins, and severely injured leaves had a tendency to curl up close to the stem. The color after injury in this plant was a light reddish-brown. (Plate VI, Fig. 23.) In geranium most of the injury was on the edge of the leaf, which, on drying, curled up strongly. Occasionally very definite intercostal spots were present. (Plate VI, Fig. 22.)

III. Relative Susceptibility of Plants to Sulphur Dioxide

In connection with the field observations on the effect of sulphur dioxide on plants in the Trail-Northport area and in fumigation experiments at Summerland, B.C., some experience was gained in regard to the relative susceptibility of a number of species which it is thought may be of use in similar work elsewhere.

Coniferous Species

At the season of the year when growth is most active, the order of susceptibility, beginning with the most susceptible coniferous species and arranged in order of increasing resistance, is as follows: larch, Douglas fir, yellow pine, Engelmann spruce, white pine, hemlock, lodgepole pine, silver fir, white fir, and red cedar.

Larch is very susceptible in the spring but becomes quite resistant to sulphur dioxide later in the growing season. In the areas subjected to fumes from the Trail smelter, injury to larch was almost invariably confined to the month of May, and if this species escaped injury in May the possibility of injury later in the growing season would be remote, even though sulphur dioxide of the usual order of intensity and duration continued to be present. From field experience, early May is the only period of the growing season when larch is susceptible to killing by sulphur dioxide. Fumigations which occur in June, July and August, although they may cause marking, if of sufficient intensity and duration, have never been known to kill the larch.

Douglas fir and yellow pine are not as susceptible as some of the more sensitive broad-leaved trees and shrubs to acute injury, but may suffer from the effects of chronic injury induced by the gradual accumulation of sulphur in the needles over a period of years. Very young seedlings of these two species were found to be quite readily marked with concentrations of about 1.00 p.p.m. for about nine hours.

With regard to older Douglas fir and yellow pine trees, varying in age from about 5 to 30 years and growing under natural conditions, these were found to be very resistant to sulphur dioxide gas in the autumn and winter, when high concentrations for relatively long periods were required to injure them. In the early part of the growing season they were more susceptible, but it is worthy of note that in the field, chronic injury, as manifested by a retardation in growth, was found to be present over a very much greater area than the zone where definite acute markings could be found.

The other species, such as lodgepole pine and cedar, were not injured except at points relatively close to the smelter, where the gas concentrations were considerably higher than farther afield. Here again, the effects of chronic injury would be more important than acute symptoms in any study of smelter fume damage.

Broad-leaved Trees and Shrubs

In the smelter fumes area, the birch and bitter cherry were the species marked most frequently by sulphur dioxide, followed closely by aspen and alder. The more sensitive broad-leaved trees and shrubs, although found to be quite severely marked in the area within 15 miles from the smelter in certain years, apparently were much more resistant to killing than the conifers. In the zone where there were very few conifers left alive, most of these broad-leaved trees and shrubs were still present. The following list gives the scale of susceptibility in order of increasing resistance from left to right. The species in each column are not necessarily of equal susceptibility, but generally those listed first are thought to be most susceptible :

Broad-leaved Trees

Birch	Apple	Chokecherry	Elm
Bitter cherry	Mountain maple	Elder	Horse chestnut
Aspen	Red hawthorn	Plum	Silver maple
	Willow	Pear	
	Cottonwood	Cherry	
	Mountain ash	Peach	
	Locust	Apricot	
	Alder		

Ninebark and ocean spray were the two most susceptible shrubs and throughout the field studies were found to be valuable indicator plants in the early part of the growing season before the effects of heat and drought became manifest in discolorations of the foliage. Ninebark was found to be quite as susceptible as alfalfa, the most sensitive of the crop plants. However, this shrub was not quite as susceptible to sulphur dioxide as the larch at its peak of susceptibility. In early May of 1930 and 1936, when the most widespread markings occurred on larch, the distribution in regard to ninebark was not quite as extensive. Among other shrubs found useful as indicator plants may be mentioned the mountain laurel and service berry. The relative susceptibility is indicated below in the same manner as in the case of the broad-leaved trees:

Shrubs

Ninebark	Mountain laurel	Mock orange	Lilac
Ocean spray	Hazel	Snow berry	Spiraea
Service berry	Grape	Thimbleberry	Oregon grape
	Raspberry	Elderberry	Buck brush
	Currant		Buffalo berry
	Gooseberry		Dogwood
	Blackberry		Sumac
			Kinnikinnick

Field Crops and Garden Species

Alfalfa, the most important crop plant in this district, was found to be the most susceptible to acute sulphur dioxide markings. Especially on irrigated or sub-irrigated lands where more than one crop was harvested during a season, this plant remained sensitive to sulphur dioxide over a longer period than either larch or ninebark. More acute markings were always found in May and June than in July and August. This was due to the higher humidity and other conditions more favorable for sulphur dioxide injury in May and June. The experimental studies at Summerland, B.C., served to confirm the field observations in regard to the susceptibility of alfalfa in comparison with other plants.

From observations on experimental plots at the site of the Stroh recorder, barley was found in the seedling stage to be more susceptible than rye, wheat or oats. Later, rye was found to be marked more readily than barley. Markings were never observed on oats at the Stroh plots, even when barley and rye showed markings on most of the leaves. However, Zimmerman and Crocker (19) found that oats were almost as susceptible as barley, the susceptibility being about equal to that of rye and much greater than that of wheat. This is quite different from our field observations. The following is the susceptibility scale of crop plants with increasing resistance from left to right:

Crop Plants

Alfalfa	Barley	Sweet clover	Field corn
	Rye	Wheat	
	Red clover	Oats	
	White clover		
	Timothy		

A wide variety of vegetables and flowers are grown in gardens in this area, even close to the smelter. With the exception of the immediate vicinity of Trail, where at times very severe markings occurred on garden plants, sulphur dioxide conditions even in 1930 and 1931 did not noticeably affect the growth of most species. The following garden plants are shown in order of increasing resistance to sulphur dioxide, from left to right, based on field experience:

Garden Plants

Lettuce	Rhubarb	Potato	Asparagus
Beet	Parsnip	Onion	
Radish	Carrot	Cabbage	
Squash	Cauliflower	Pea	
Brussels sprouts	Bean	Pumpkin	
Spinach	Turnip	Horseradish	
	Egg plant	Cantaloupe	
	Vegetable marrow	Citron	
	Tomato	Sweet corn	
	Cucumber		
	Swiss chard		

With regard to flowers, the following susceptible species were observed to develop acute symptoms of sulphur dioxide injury. Columbine, sweet william and tulip were marked at Northport following the gas visitation of May 2, 1936. Morning glory, geranium, petunia, zinnia, aster, hollyhock and dahlia were marked in the region 12 miles south of Trail in August, 1936. More resistant species which have been marked occasionally with higher concentrations of sulphur dioxide near Trail are peony, rose, phlox, veronica, verbena, snap dragon, pansy, and celosia. Chrysanthemums appear to be extremely resistant.

Among susceptible grasses and weeds may be listed June grass, Kentucky blue grass, peppergrass, dandelion, mullen, lamb's quarters, ragweed, and redroot pigweed. Milkweed, Russian thistle, shepherd's purse, and tumbling mustard are comparatively resistant to sulphur dioxide.

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CHAPTER IV

**THE SULPHUR CONTENT OF TREES AND SHRUBS
IN RELATION TO SULPHUR DIOXIDE
IN THE ATMOSPHERE**

BY MORRIS KATZ AND A. W. McCALLUM

Introduction

This study was undertaken to determine the relation between the sulphur content of the leaves of some coniferous trees and shrub species, and the sulphur dioxide in the atmosphere under field conditions such that the gas visitations are of variable concentration, duration and frequency. An attempt has been made to determine the decrease in sulphur content of the vegetation with increase in distance from Trail, B.C. and thereby arrive at the limits of penetration of sulphur dioxide.

Furthermore, in connection with the field surveys of the condition of trees, shrubs and crops in the smoke zone, it was considered useful to know the sulphur content of the vegetation not only in the area of highest frequency of sulphur dioxide occurrence but also in the more remote parts of the main Columbia valley and its various tributary valleys. In relation to the smelter smoke investigation as a whole, this study is considered to form a part of the basic studies of which the other component parts are the investigations of the atmosphere, soils, forest and agricultural conditions; and serves to supplement the picture of the effect of smelter operations in this area.

The work was undertaken during the late summer of 1930 with collections of leaves of yellow pine, Douglas fir, larch, aspen, hazel and ninebark, in the area south of Trail, B.C., both in the valley of the Columbia River and in the tributary valleys. Most of these collections were taken in the adjacent part of Stevens County, Washington. Collections of these species were also made at a number of points in northeastern Washington and southeastern British Columbia, in areas remote from the smoke zone, in order to determine the normal range in sulphur content. In 1931 the work was confined to yellow pine and Douglas fir, additional collections being made in the smoke zone, while the control collections were augmented considerably. In 1934 a further collection of the six species used in 1930 was made, whereas in 1935 and 1936 the collections were again confined to yellow pine and Douglas fir at the same locations as used previously. Samples were also taken to determine the influence of increasing altitude upon sulphur content and the absorption, if any, of sulphur dioxide by conifers during the winter. The winter absorption has been studied each season since 1932.

Apparently normal, uninjured foliage was collected for the most part in the smoke zone, unless indicated otherwise in the tables. Composite samples of the leaves were taken of at least three of each species at each location. In the conifer-

fers the leaves of the different years' growth were collected separately, the last three years' growth of needles being taken from yellow pine and the last four from Douglas fir.

Literature Review

There are many references in the literature to the sulphur content of plants in industrial regions but very few reports of comprehensive investigations which show the relation between sulphur content of the vegetation and sulphur dioxide in the atmosphere with increasing distance from the source of emission. Schroeder and Reuss (14) report the results obtained by Freytag on clover hay indicating a higher sulphuric acid content in the ash of samples in a smoke area compared with those unaffected by smoke. Schroeder and Reuss show that in an industrial area near Bonn, badly injured one-year-old pine needles contained 0.460% sulphuric acid, and dead needles 0.517%; whereas healthy needles, collected some distance away from the source of pollution in the same region, varied from 0.101% for one-year-old needles to 0.076% for three-year-old needles.

With regard to the relation between sulphur content and injury by sulphur dioxide, Wislicenus (17) is of the opinion that a short gas visitation with high concentrations may cause the death of a plant without any detectable increase in the sulphur content, whereas in the case of chronic injury high sulphur values may be found.

Haselhoff and Lindau (7) express the opinion that a general mean value for sulphur content of healthy plants is not a criterion on which to base opinions of smoke damage since the sulphur content is subject to great variation in normal plants. These authors consider that chemical analyses of plants are valuable in determining smoke damage in a qualitative sense only but should not be used to determine the degree of damage. This view is supported by Tatlock and Thomson (15) who found that healthy plants often contain much more sulphur than injured plants. Grass grown in a fairly pure atmosphere was found to contain up to 0.3% sulphur trioxide which could be increased to 1% without injury. Damaged oak leaves contained 0.202% sulphur trioxide as against 0.42% in uninjured leaves, and similarly healthy birch leaves contained 0.86% sulphur trioxide as compared with 0.248% in injured leaves. Hamburger (5) also reports a higher sulphur trioxide content in healthy plants than in injured ones in an industrial area.

Mitchell (12) in a study of the sulphur content of grain and alfalfa in four widely separated smelter districts came to the conclusion that, although the sulphur content is invariably increased by exposure to sulphur dioxide, an increase may also be brought about by absorption from high sulphate soils, and that evidence of absorption is definitely not evidence of injury, but only of exposure, there being no quantitative relationship between increase in sulphur content and degree of injury.

Haselhoff, Bredemann and Haselhoff (6) consider that acute injury in conifers is not always accompanied by an increase in the sulphuric acid content of leaves. Beran and Reckendorfer (1) express a similar opinion. These authors studied the sulphur content of Scotch pine at various distances from a railway line and an industrial works. No definite conclusions could be drawn from the data since the method of sampling was not sufficiently comprehensive. In the case of chronic injury, Lorenz (10) considers that analyses of needles of conifers in sufficient number and from numerous locations may indicate whether one is dealing with smoke damage. A limited number of analyses are given in this paper showing the increase in smoke effect in percentage of sulphur trioxide content of normal needles. The increase varies from 50 to 90% in the case of spruce, and 9 to 20% in the case of pine.

With regard to the precautions to be taken in an investigation of this kind, Kock (9) advocates the use of control specimens obtained from similar areas in a smoke-free region for comparison with the sulphur values found in the smoke zone. Care must be taken, however, not to compare absolute values of sulphur content since these vary according to the plant species, the soil and other factors. Bredemann and Radeloff (2) are of the opinion that analyses of the sulphur dioxide content of leaves are valuable in diagnosis if carried out immediately after the injury has taken place. In the case of old injury, however, the analysis must be carried through for estimation of the sulphate content.

Von Rusnov (13), from a considerable number of analyses of conifer leaves, found that the sulphur in the leaves decreased as the distance from the source of sulphur dioxide increased. The sulphate content of the soil was found to be a relatively unimportant factor in this study. For spruce needles the sulphur content close to various sources of pollution ranged as high as 1.2%, expressed as sulphur trioxide, whereas the normal value was given as 0.19%. J. K. Haywood (8) studied the relative amounts of sulphur in the leaves and ash of foliage from trees in the vicinity of smelters in Tennessee, at Redding, California, and in the region of Washoe and Butte smelters in Montana. Haywood estimated zones of smelter damage to forests from chemical analyses of leaves on the assumption that only visibly injured foliage contains abnormal amounts of sulphur trioxide derived from the atmosphere.

Cohen and Ruston (3) report sulphur values as high as 1.98%, expressed as sulphur trioxide, in the leaves of laurel in the Leeds industrial district, whereas in an area free from pollution the content was 0.3%. They conclude that sulphur accumulates in leaves mainly as sulphates when exposed to sulphur dioxide in the atmosphere and that the sulphur content increases with age.

McCool and Johnson (11) studied the sulphur content of leaves of plants at various distances from the industrial centres of Camden, New Jersey, East St. Louis, Illinois, and St. Louis, Missouri. They found on the whole a significant decrease in sulphur content with increase in distance from these centres.

Fisher, Goldsworthy and Griffin (4), and more recently Griffin, *et al.* (4), of the U.S. Department of Agriculture, have reported to the International Tribunal in the Trail smelter case the results of an investigation on the sulphur content of vegetation in the northern part of Stevens County, Washington. They found that sulphur dioxide in the atmosphere increased the sulphur content of the various species investigated for a distance of about 54 miles from Trail in 1930, and for a somewhat shorter distance in 1936 in the main Columbia River valley. The extent of sulphur dioxide penetration found by these investigators agrees substantially with the results recorded here.

Methods of Analysis

Several ounces of leaves were collected for each sample. The leaves were carefully separated from the petioles, stems and small twigs in the laboratory and dried at room temperature. The samples were then finely ground in a small mill, and the total sulphur content determined by either one of the following two methods. The moisture content was determined on a fresh sample and the results reported as percentage total sulphur on the dry basis.

1. About 2 gm. of dried material (finely ground) was mixed in a 100 cc. nickel crucible with 7 gm. of sodium carbonate (anhydrous) and about 2 cc. of water added. Then about 10 gm. of sodium peroxide was added in small portions with constant stirring until the mixture became granular. The crucible was then heated gradually until complete fusion occurred (without ignition). The contents of the crucible were then allowed to cool, about 2 gm. of sodium peroxide was added, and the crucible reheated until fusion again took place. The heating was continued for about 10 min. longer, with constant stirring. The crucible was then cooled, and the contents washed out in a 600 cc. beaker with 100 cc. of distilled water. The solution was made slightly acid by the addition of hydrochloric acid followed by 10 cc. of 10% barium chloride. The barium sulphate was determined gravimetrically in the usual manner.

2. About 0.5 gm. of finely divided plant material was placed in a Parr bomb and mixed thoroughly with about 10 gm. of fine sodium peroxide and 1 gm. of potassium chlorate as accelerator. The bomb was then sealed and the contents fused by connecting to the terminals of a 6-volt battery. The fused mixture was dissolved in water, made acid by the addition of hydrochloric acid, filtered, and the sulphur was precipitated with barium chloride. The barium sulphate was then determined gravimetrically.

Sampling Errors

The data in Table I indicate the variation in sulphur content of conifer leaves taken from adjoining trees in the vicinity of Summerland, B.C., at the site of the fumigation experiments on conifers in 1931, prior to sulphur dioxide treatment, and also within the smoke zone at a point 15 miles south of Trail, B.C.,

TABLE I
THE SULPHUR CONTENT OF CONIFER LEAVES FROM ADJOINING TREES

	Age of leaves, years			
	1	2	3	4
	Per cent total sulphur			
<i>Douglas fir, Summerland, B.C. (control zone)</i>				
Tree No. 1	0.02	0.08	0.11	0.12
Tree No. 4	0.06	0.10	0.09	0.11
Tree No. 18	0.11	0.13	0.17	0.16
Tree No. 76	0.06	0.09	0.09	0.10
Trees Nos. 86, 87, 88	0.02	0.07	0.07	0.12
Average	0.05	0.09	0.11	0.12
Standard error	0.017	0.01	0.018	0.01
<i>Yellow pine, Summerland, B.C. (control zone)</i>				
Tree No. 13	0.06	0.09	0.09	
Tree No. 14	0.08	0.12	0.11	
Tree No. 113	0.07	0.07	0.06	
Tree No. 150	0.06	0.06	0.04	
Tree No. 155	0.07	0.08	0.09	
Tree No. 158	0.05	0.05	0.05	
Tree No. 277	0.05	0.02	0.03	
Tree No. 283	0.06	0.04	0.04	
Average	0.06	0.07	0.06	
Standard error	0.004	0.011	0.010	
<i>Douglas fir, 15 miles south of Trail, B.C. (smoke zone)</i>				
Tree No. 201	0.32	0.53	0.58	0.58
Tree No. 202	0.32	0.48	0.55	0.56
Tree No. 203	0.34	0.59	0.62	0.59
Tree No. 204	0.31	0.51	0.57	0.60
Average	0.32	0.53	0.58	0.58
Standard error	0.006	0.023	0.014	0.008
<i>Yellow pine, 15 miles south of Trail, B.C. (smoke zone)</i>				
Tree No. 205	0.30	0.37	0.42	
Tree No. 206	0.29	0.33	0.36	
Tree No. 207	0.27	0.34		
Tree No. 208	0.28	0.36	0.43	
Average	0.29	0.35	0.40	
Standard error	0.007	0.009	0.022	

in the main Columbia River valley. The extent of the variation in sulphur content is on the whole greater in the case of Douglas fir than yellow pine. In view of this factor of individual variation the method used in this work of taking a composite sample from a number of trees at each point gives more reliable information than if individual trees only were sampled. The sampling errors for the groups of trees shown in Table I lie between the limits of 0.004 and 0.023% sulphur.

With regard to the reliability of the sulphur analyses, the analytical data on 39 sets of duplicate samples indicated an average deviation between pairs of 0.015% sulphur. This is due in part at least to sampling errors.

The Normal Sulphur Content of Trees and Shrubs

The proper interpretation of data relating to the increase in sulphur content of vegetation, located in an area of sulphur dioxide occurrence, requires a knowledge of the amount of sulphur in the foliage which is derived from the soil and which would be present normally in these plants if grown in an atmosphere free from sulphur dioxide. An approximate idea may be obtained by the analyses of a sufficient number of collections from locations representing similar soil types in areas remote from the smoke zone. From the data at hand this soil effect is found to introduce variations in the normal sulphur content of foliage depending upon the composition of the soil and the plant species. In certain localities, presumably where sufficient sulphur is available in the soil, the sulphur content of the needles of conifers increases with age, while at other points it remains practically constant from year to year. Similarly, in the case of larch and other species such as hazel, ninebark, and aspen, there are variations in the normal sulphur content depending upon the particular location in which the sample was collected. However, if a sufficiently large number of collections are available, as in the present work, the normal range in sulphur content for each species for a given region may be evaluated with considerable accuracy.

The data in Table II indicate the normal variations in sulphur content of Douglas fir and yellow pine at many points in Washington and British Columbia. With regard to yellow pine, the minimum sulphur content in one-year-old leaves may be as low as 0.01%. The highest value found was 0.29%, with the average close to 0.10%. With regard to the two- and three-year-old leaves, the values vary from 0.02 to 0.21%, with averages of 0.108 and 0.113% respectively. In some instances the sulphur content of the yellow pine appears to vary but little from year to year; in others, there is an increase with age. The normal average sulphur content of Douglas fir foliage, as shown by these collections, increases from 0.082% in the current needles to 0.149% in three-year-old needles.

In Table III the results obtained from the analyses of the control collections of larch, aspen, hazel and ninebark are given. As shown by this table larch varies in sulphur content from 0.02 to 0.22%, depending on the site, the average being

0.12%. Hazel shows a range of variation from a minimum of 0.09 to a maximum of 0.26%, with the average 0.17; aspen varies from 0.06 to 0.25%, with the average 0.09%; and ninebark from 0.03 to 0.26%, with the average 0.13%.

TABLE II

THE SULPHUR CONTENT OF YELLOW PINE AND DOUGLAS FIR—CONTROL COLLECTIONS

Description of location	Total sulphur on dry basis, %						
	Yellow pine, year's leaves			Douglas fir, year's leaves			
	1930	1929	1928	1930	1929	1928	1927
<i>Collections of July, 1930</i>							
Condon Ferry, Wash. -----	0.05	0.14	0.14	-----	-----	-----	-----
Curlew, " -----	0.11	0.05	0.11	0.12	0.10	0.13	0.18
Clark, " -----	0.01	0.05	0.18	0.01	0.11	0.09	0.10
Entiat, " -----	0.09	0.06	0.10	0.10	0.14	0.15	0.15
Bridgeport -----	0.07	0.09	0.07	-----	-----	-----	-----
Lincoln, " -----	0.13	0.13	0.14	0.08	0.09	0.08	0.10
Slocan, B.C. -----	0.29	0.16	0.19	-----	-----	-----	-----
Kaslo, " -----	-----	-----	-----	0.22	0.12	0.20	0.18

Collections of July, 1931

	1931	1930	1929	1931	1930	1929	1928
1 mi. south of Echo, Wash. -----	0.06	0.17	0.10	0.08	0.12	0.24	0.23
6 mi. east of Chewelah -----	0.02	0.02	0.06	0.06	0.04	0.09	0.11
10 mi. west of Addy -----	0.10	0.11	0.07	0.03	0.10	0.16	0.12
6 mi. west of Kettle Highway (near Dollar Mt.), Wash. -----	0.12	0.20	0.17	0.08	0.14	0.21	0.24
11 mi. from mouth of Onion Creek. -----	0.15	0.09	0.12	0.06	0.15	0.19	0.20
Near Cascade Mt., B.C. -----	0.06	0.09	0.10	0.05	0.06	0.10	0.09
Near Osoyoos, B.C. -----	0.08	0.05	0.06	0.04	0.04	0.04	0.03
Colville Forest Reserve, Wash. -----	-----	-----	-----	0.07	0.11	0.12	0.12
Kettle Valley, 10 mi. from mouth. -----	0.10	0.21	0.08	0.07	0.11	0.11	0.12

Collections of December, 1931

Near Echo (4 mi. south) -----	0.09	0.11	0.13	0.14	0.21	0.19	0.24
2 mi. north of Aladdin -----	0.10	0.11	0.11	0.10	0.15	0.15	0.17
Average -----	0.096	0.108	0.113	0.082	0.112	0.141	0.149

TABLE III
THE SULPHUR CONTENT OF LARCH, HAZEL, NINEBARK AND ASPEN—
CONTROL COLLECTIONS

Description of location	Total sulphur on dry basis, %			
	Larch	Hazel	Ninebark	Aspen
<i>Collections of July, 1930</i>				
3 mi. north of Newport, Wash.	0.02	0.15	0.16	0.17
Curlew, Wash.	0.05	—	0.07	0.17
Clark, Wash.	—	—	—	0.20
Kaslo, B.C.	0.14	0.19	—	0.21
Lincoln, Wash.	—	—	0.09	0.25
<i>Collections of July, 1931</i>				
1 mi. south of Echo (toward Colville).	0.22	0.18	—	—
6 mi. east of Chewelah, Wash.	0.09	0.09	0.03	0.18
10 mi. west of Addy, Wash.	0.03	—	0.26	0.11
6 mi. west of Kettle Highway (near Dollar Mt.)	—	0.24	—	—
11 mi. from mouth of Onion Creek	—	—	0.04	0.19
Near Cascade Mountain, B.C.	0.12	0.13	0.06	0.13
Osoyoos, B.C.	0.06	—	—	0.13
Colville Forest Reserve	0.16	0.20	0.11	0.21
Kettle Valley, 10 mi. from mouth	—	—	0.10	0.09
10 mi. up Big Sheep Creek from Forks	0.19	—	—	0.13
<i>Collections of August, 1934</i>				
Echo Valley, 7 mi. north of Colville	0.18	0.26	0.08	0.08
Loon Lake, Wash.	0.15	—	0.09	0.12
Sullivan Lake, Wash.	0.13	0.14	0.13	0.16
Newport, Wash.	0.13	0.16	0.05	0.08
Sandpoint, Idaho	0.12	—	0.06	0.06
Near Curlew, Wash.	0.12	—	0.05	0.06
Salmo, B.C.	0.15	0.18	—	0.09
Kaslo, B.C.	0.11	0.19	—	0.06
5 mi. south of Ainsworth, B.C.	0.14	0.12	—	0.06
Average	0.12	0.17	0.09	0.13

The above variations in the sulphur content of each species must be borne in mind in determining the limit of distribution of gas in the atmosphere by means of sulphur analyses of foliage.

Limits of Distribution of Sulphur Dioxide 1930-1931

The sulphur dioxide conditions in the Columbia River valley south of Trail, B.C., have already been discussed in Chapter II. In this chapter it was pointed out that the region of greatest frequency of sulphur dioxide occurrence and highest concentration of gas was situated in the area 5 to 15 miles south of Trail. An intermediate zone of less frequent gas visitations and lower sulphur

TABLE IV
THE SULPHUR CONTENT OF DOUGLAS FIR AND YELLOW PINE
Collections made during July and August, 1930 and 1931

Approx. distance from Trail, miles	Description of location	Total sulphur on dry basis,%									
		Yellow pine, year's leaves				Douglas fir, year's leaves					
		1931	1930	1929	1928	1931	1930	1929	1928	1927	
Columbia River Valley											
11	International Boundary ..	—	0.18	0.33	—	—	—	—	—	—	
16	Near Stroh ranch	0.21	0.37	0.39	—	0.36	0.50	0.58	0.61	—	
19	Mouth Deep Creek	—	0.30	0.45	0.45	—	0.29	0.48	0.74	—	
19	Mouth Sheep Creek	—	0.41	0.43	0.46	—	0.22	—	0.70	—	
28	Marble	—	0.25	0.47	0.42	—	0.18	0.40	0.71	—	
39	Bossburg	—	0.24	0.50	0.35	—	0.50	0.60	0.86	1.03	
43	Evans	0.21	0.39	0.34	—	—	—	—	—	—	
47	Marcus	0.15	0.28	0.26	—	0.24	0.53	0.62	0.61	—	
52	Kettle Falls	0.16	0.23	0.22	—	0.19	0.27	0.28	0.34	—	
58	6 mi. south Kettle Falls ..	0.16	0.19	0.20	—	0.16	0.24	0.26	0.34	—	
62	10 mi. south Kettle Falls ..	0.12	0.15	0.17	—	0.24	0.35	0.36	0.39	—	
64	12 mi. south Kettle Falls ..	—	0.22	—	0.28	—	—	—	—	—	
70	18 mi. south Kettle Falls ..	0.14	0.18	0.20	—	0.10	0.13	0.14	0.16	—	
72	20 mi. south Kettle Falls ..	—	0.19	0.30	0.23	—	—	—	—	—	
89	Cedonia	—	0.17	0.20	0.22	—	0.15	0.16	0.20	0.24	
89	Cedonia	0.12	0.16	0.20	0.23	0.17	0.22	0.22	0.23	—	
Approx. distance from Columbia River	Tributary Valleys										
	Cedar Creek (near Inter- national Boundary)										
3	Cedar Creek bridge	—	—	—	—	—	0.17	0.46	0.60	—	
4.5	1.5 mi. up East Fork	—	—	—	—	—	0.17	0.28	0.29	—	
6	Near Terry's ranch	—	—	—	—	—	0.12	0.28	0.36	0.46	
	Deep Creek—										
0.3	Mouth of Deep Creek	—	0.30	0.45	0.45	—	0.29	0.48	0.74	—	
2.5	Near Rosendahl ranch	—	0.20	0.25	—	—	0.22	0.34	0.41	0.47	
3	Deep Creek cemetery	—	0.23	0.28	0.42	—	0.22	0.32	0.33	0.41	
7	3 mi. from Spirit	0.08	0.11	0.16	—	0.12	0.19	0.20	0.22	—	
10	Near Gezelius ranch	—	0.07	0.18	0.27	—	0.07	0.11	0.23	0.29	
12	Deep Lake	—	—	—	—	—	0.09	0.10	0.16	0.31	
	Sheep Creek—										
0.5	Mouth of Sheep Creek	—	0.41	0.43	0.46	—	0.22	—	0.70	—	
4.5	Velvet	—	—	—	—	—	0.21	0.23	0.57	0.39	
	Onion Creek (4 mi. south Northport)										
2	2 mi. from mouth	0.20	0.27	0.30	—	0.14	0.32	0.47	0.54	—	
6	6 mi. from mouth	0.29	0.13	0.16	—	0.16	0.30	0.35	0.38	—	
1.5	2 mi. north Williams Lake (13 mi. south Northport)	—	—	—	—	0.22	0.42	0.47	0.57	—	

NOTE. The locations of the sample stations in this and subsequent tables may be found by consulting the map, page 25.

dioxide concentrations extended from Northport (20 miles south of Trail) to Bossburg (about 39 miles south of Trail). Since 1932 there has been a marked decrease in the occurrence of sulphur dioxide in concentrations higher than 0.25 p.p.m., particularly during the growing seasons.

As will be shown in the following tables, both the effect of dilution of the gas with distance from Trail, and the improvement in gas conditions referred to above, are reflected in the sulphur content of the vegetation.

The sulphur analyses of the collections of yellow pine and Douglas fir made during 1930 and 1931 have been arranged in Table IV, in order of increasing distance from the Trail smelter in the case of those collections taken in the main valley of the Columbia River. The collections in the tributary valleys have been arranged in order of increasing distance from the Columbia River. This arrangement has been made in order to facilitate the interpretation of the data since the main path of the smoke stream is along the valley of the Columbia River, and such concentrations as are found in the tributary valleys represent the effect of air currents which cause the smoke stream to drift up the tributary valleys at times when the wind blows up these valleys from the Columbia River.

The leaves of the Douglas fir collections of 1930 and 1931 in the smoke zone show a marked increase in sulphur content with age, owing to the presence of

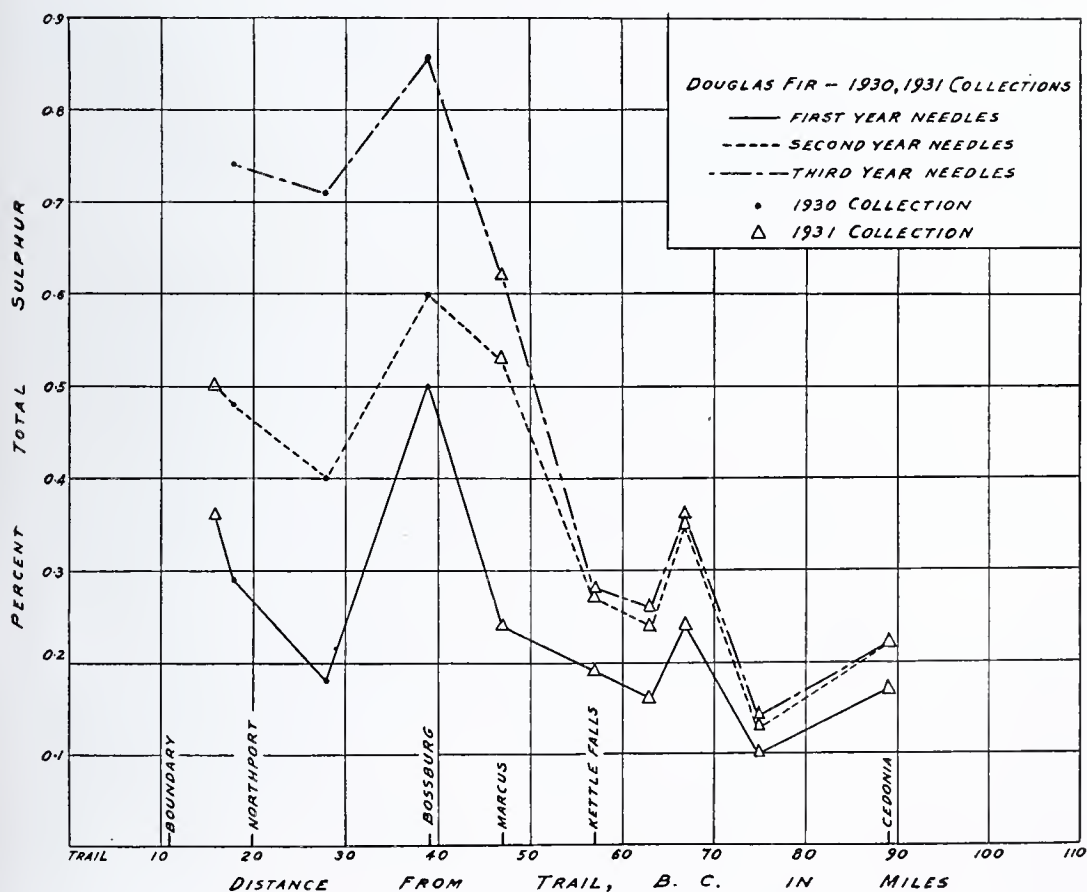


FIG. 1.—The sulphur content of vegetation in northern Stevens County, Wash.

sulphur dioxide. This increase is particularly noticeable in the region between the International Boundary and Bossburg (see Fig. 1). From Bossburg southward the curves for the first-, second- and third-year leaves show a decided drop in sulphur content to Marcus and Kettle Falls. From Kettle Falls southward the values are substantially normal and compare favorably with the normal sulphur content in leaves of similar age. These data indicate that in 1930 and preceding years the gas stream, in proceeding down the Columbia River valley, was diluted very rapidly in the area between Bossburg and Kettle Falls. The vicinity of Kettle Falls marked the farthest limit of penetration of the gas stream at that time.

The 1930-1931 data for yellow pine indicate a similar trend to that of the fir for these years, with this difference—that the pine leaves appear to absorb sulphur dioxide to a lesser extent; therefore the yearly increase of sulphur in the leaves is relatively smaller (Fig. 2). The sulphur values are abnormally high from the International Boundary to Bossburg. From Bossburg to Marcus there is a pronounced reduction in sulphur content. Between Marcus and Kettle Falls the values are only slightly higher than normal, and beyond Kettle Falls the values are within the normal range for this species.

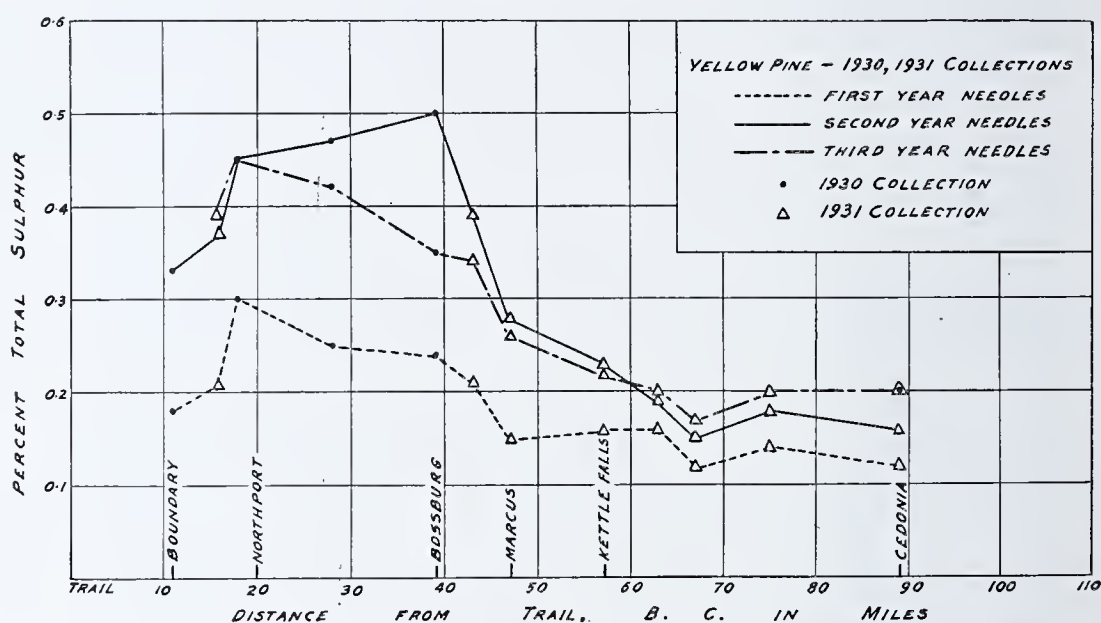


FIG. 2.—The sulphur content of vegetation in northern Stevens County, Wash.

The 1930 analyses of aspen, ninebark, and hazel, shown in Table V, serve to bring out the high sulphur content of vegetation within the smoke zone in a rather striking way. As shown by Fig. 3, the sulphur content is abnormally high in the Columbia valley from Trail to Bossburg. The aspen collections show a decided drop in sulphur content from Marble to Bossburg, and the ninebark and hazel show a similar decrease from the vicinity of Northport to Marble. Below Bossburg the values drop to a substantially normal level in the neighborhood of Kettle Falls.

TABLE V

THE SULPHUR CONTENT OF LARCH, HAZEL, NINEBARK, AND ASPEN IN THE
NORTHPORT AREA

(Collections made in July, 1930 and August, 1934)

Approx. distance from Trail, miles	Description of location	Total sulphur on dry basis, %							
		Larch		Hazel		Ninebark		Aspen	
		1930	1934	1930	1934	1930	1934	1930	1934
Columbia River Valley									
6	Beaver Creek, B. C.....	—	0.71	0.69*	0.63	0.65*	—	0.97*	0.7
11	International Boundary....	0.56	0.53	0.70*	0.42	0.53*	0.45	0.73*	0.60
15	Wood Spur	—	0.41	—	0.42	—	—	—	0.52
17	Big Nigger Creek	—	0.45	—	0.32	—	—	—	0.53
19	Mouth of Deep Creek.....	0.49	0.41	0.52	0.30	0.83	0.29	0.83	0.44
19	Mouth of Sheep Creek.....	0.43	0.39	0.68*	0.44	0.50*	—	0.23	0.45
21	Northport	—	0.45	—	0.38	—	—	—	0.52
25	Mouth of Onion Creek.....	—	0.38	—	0.36	—	0.19	—	—
26	Pepoon Lake road	—	0.34	—	0.38	—	0.11	—	—
27	Rattlesnake Creek	—	—	—	0.33	—	0.12	—	0.32
28	Crown Creek and Marble..	0.57	0.38	0.46	0.36	0.36	0.18	1.06	0.36
32	China Bend	—	0.31	—	0.28	—	0.16	—	0.50
32	Mouth of Flat Creek	—	0.24	—	0.27	—	—	—	0.50
39	Bossburg	0.58	0.30	0.47	0.33	0.35	—	0.68	0.48
43	Evans	—	0.34	—	0.25	—	0.12	—	0.39
47	Marcus	—	—	—	0.27	—	0.11	—	—
52	Kettle Falls	—	—	0.24	0.25	—	—	0.38	0.20
71	19 mi. south Kettle Falls	—	—	—	—	—	—	0.37	—
89	Cedonia	—	—	—	—	0.14	—	0.23	—
Approx. distance from Columbia River	Tributary Valleys								
3	Cedar Creek—								
4.5	Cedar Creek bridge	0.50	0.25	0.42	0.24	0.46	0.14	0.49	0.18
6	East Fork	0.42	0.32	—	0.23	—	—	0.35	0.33
6	East Fork	0.37	0.18	—	0.18	—	0.14	—	0.15
	Cedar Lake	—	0.21	—	0.24	—	0.12	—	0.27
	Deep Creek—								
0.3	Mouth of Deep Creek ...	0.49	0.41	0.52	0.30	0.83	0.29	0.83	0.44
1.5	Deep Creek dam	—	0.31	—	0.26	—	0.12	—	0.36
2.5	Near Rosendahl ranch.....	—	0.21	—	0.24	—	—	—	0.13
3	Deep Creek cemetery	0.50	—	0.50	—	0.41	—	0.36	—
5	Near Maki ranch	—	0.22	—	0.29	—	0.08	—	0.26
10	Near Gezelius ranch	0.26	0.16	0.34†	0.19	—	0.12	—	0.07
12	South end of Deep Lake ..	0.18	0.14	0.27	0.21	0.14	0.08	0.21	0.10
	Sheep Creek—								
0.5	Mouth of Sheep Creek...	0.43	0.40	0.68*	0.44	0.50*	—	0.23*	0.45
3	Near Forks, Big & Little	—	0.43	—	0.36	—	0.16	—	0.46
4.5	Sheep	—	—	—	—	—	—	—	—
	Velvet	0.38†	—	0.25†	—	0.63	—	0.45†	—
6	Near Paterson	—	0.22	—	0.27	—	0.07	—	0.07
1.5	Brodie Basin	—	0.31	—	0.28	—	0.13	—	0.18
	Onion Creek—								
	Mouth of Onion Creek.....	—	0.38	—	0.36	—	0.19	—	—
2	2 mi. up Onion Creek.....	—	0.22	—	0.24	—	—	—	0.23
5	5 mi. up Onion Creek.....	—	0.18	—	—	—	0.06	—	0.18
	Flat Creek Area								
4.5	Bordering Forest Reserve, Elevation 2600 feet	—	0.27	—	0.24	—	0.10	—	0.32
7	Colville Forest Reserve, Elevation 2900 feet	—	0.15	—	0.26	—	0.11	—	0.21
3	Williams Lake	—	0.26	—	0.20	—	0.13	—	0.27

* Foliage apparently injured by sulphur dioxide.

† Discolored foliage.

‡ This collection taken at a point 7 miles from mouth of Deep Creek.

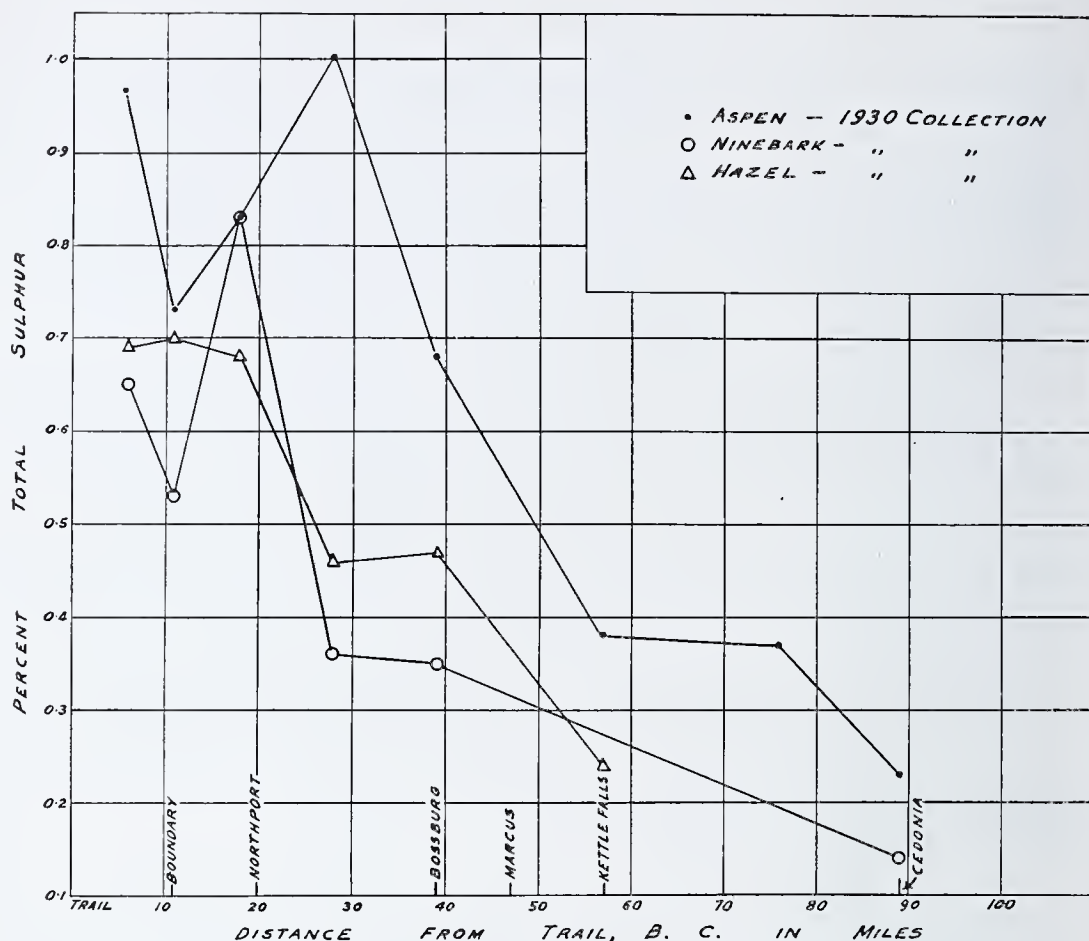


FIG. 3.—The sulphur content of vegetation in northern Stevens County, Wash.

Within the main valley of the Columbia River the area in which appreciable sulphur dioxide concentrations occurred during 1930 extended as far south as Bossburg. From Bossburg to Kettle Falls extensive dilution of the gas stream took place, and from Marcus to Kettle Falls the concentrations dropped to a point where the absorption by vegetation was not appreciable.

With regard to the tributary valleys of the Columbia River, the indications are that sulphur dioxide did not spread very far up these valleys. Thus, in the valley of Cedar Creek, which is situated near the International Boundary, substantially normal values for sulphur content in vegetation were reached about six miles from the Columbia River. In Deep Creek valley the sulphur content of pine and fir decreased rapidly from the mouth of the creek to a point about three miles east of the Columbia River. About seven miles from the mouth of the creek there was practically no indication of absorption of sulphur dioxide by the vegetation. On the west side of the Columbia River the indications are that the smoke stream penetrated up Sheep Creek valley as far as Velvet.

The Limits of Distribution of Sulphur Dioxide in 1934, 1935, and 1936

The sulphur analyses of the foliage collections made in the fall of 1934 indicate a very marked reduction in the extent of penetration of the gas stream

TABLE VI
THE SULPHUR CONTENT OF DOUGLAS FIR AND YELLOW PINE
Collections made in September, 1934

Approx. distance from Trail, miles	Description of location	Total sulphur on dry basis, %						
		Yellow pine, year's leaves			Douglas fir, year's leaves			
		1934	1933	1932	1934	1933	1932	1931
Columbia River Valley								
6	Beaver Creek, B. C.	0.21	0.36	—	—	—	—	—
11	International Boundary....	0.17	0.36	0.51	—	—	—	—
15	Wood Spur	0.17	0.41	0.41	0.14	0.43	0.57	—
17	Big Nigger Creek.....	0.25	0.45	0.42	—	—	—	—
19	Mouth of Deep Creek.....	0.21	0.42	0.36	0.13	0.30	0.34	0.43
19	Mouth of Sheep Creek.....	0.22	0.41	0.41	—	—	—	—
21	Northport bridge.....	0.16	0.35	0.40	—	—	—	—
25	Mouth of Onion Creek.....	0.19	0.32	0.34	0.21	0.37	0.48	0.45
27	Rattlesnake Creek.....	0.21	0.31	0.35	0.19	0.28	0.26	0.36
28	Crown Creek.....	0.14	0.18	0.21	0.18	0.30	0.37	0.41
32	China Bend.....	0.12	0.20	0.22	0.09	0.41	0.47	0.44
33	Mouth of Flat Creek.....	0.12	0.22	0.27	0.19	0.29	0.30	0.28
39	Bossburg.....	0.22	0.22	0.28	0.21	0.30	0.39	0.49
43	Evans.....	0.19	0.22	0.24	—	—	—	—
47	Marcus.....	0.07	0.09	0.12	0.12	0.14	0.30	0.40
52	Kettle Falls.....	0.11	0.19	0.23	0.08	0.12	0.12	0.35
58	6 mi. south Kettle Falls..	0.10	0.18	0.16	—	—	—	—
64	12 mi. south Kettle Falls..	0.12	0.21	0.17	—	—	—	—
72	20 mi. south Kettle Falls..	0.10	0.09	0.12	—	—	—	—
89	Cedonia.....	0.17	0.19	0.15	—	—	—	—
Tributary Valleys								
3	Cedar Creek—	—	—	—	0.16	0.21	0.32	0.32
4.5	Cedar Creek bridge.....	—	—	—	0.10	0.22	0.26	0.26
6	East Fork Cedar Creek....	—	—	—	0.12	0.14	0.17	0.22
6	East Fork near Terry's	—	—	—	0.10	0.15	0.20	0.25
	Cedar Lake.....	—	—	—	—	—	—	—
	Deep Creek—	—	—	—	—	—	—	—
1.5	Mouth of Deep Creek.....	0.20	0.42	0.36	0.13	0.30	0.34	0.43
2.5	Deep Creek dam.....	0.11	0.16	0.21	0.13	0.26	0.32	0.41
2.5	Near Rosendahl ranch.....	0.08	0.12	0.19	0.17	0.20	0.19	0.22
5	Near Maki ranch.....	—	—	—	0.09	0.17	0.21	0.25
10	Near Gezelius ranch.....	0.06	0.07	0.08	0.09	0.09	0.11	0.18
12	South end Deep Lake.....	0.12	0.09	0.09	0.07	0.09	0.08	0.09
	Sheep Creek—	—	—	—	—	—	—	—
0.5	Mouth of Sheep Creek....	0.22	0.41	0.41	—	—	—	—
3	Near Forks (Murphy	—	—	—	0.10	0.23	0.30	0.39
6	ranch)	—	—	—	0.11	0.14	0.18	0.22
	Between Velvet and Pat-	—	—	—	—	—	—	—
	erson.....	—	—	—	—	—	—	—
1.5	Brodie Basin—	—	—	—	—	—	—	—
1.5	Brodie Basin.....	0.14	0.19	0.26	—	—	—	—
	Onion Creek—	—	—	—	—	—	—	—
2	Mouth of Onion Creek.....	0.19	0.32	0.43	0.21	0.37	0.48	0.45
5	2 mi. from mouth.....	0.13	0.16	0.18	0.15	0.25	0.29	0.31
5	5 mi. from mouth.....	0.09	0.11	0.13	0.11	0.15	0.16	0.26
	Flat Creek—	—	—	—	—	—	—	—
4.5	Mouth of Flat Creek.....	0.12	0.22	0.27	0.19	0.29	0.30	0.28
7	Bordering Forest Re-	0.10	0.15	0.21	0.11	0.15	0.16	0.18
7	serve, Elevation 2,600 ft.	—	—	—	—	—	—	—
7	Colville Forest Reserve,	—	—	—	0.08	0.07	0.10	0.09
7	Elevation 2,900 ft.....	—	—	—	—	—	—	—

since 1930. Compared with the values for the 1930 collections the sulphur contents of the 1934 collections are much lower for corresponding locations. The data for the Columbia River valley contained in Table VI are shown graphically in Figs. 4 and 5.

The curves for the yellow pine collections show an excessive amount of sulphur in the second- and third-year leaves between the International Boundary and Marble. In the same area the values for one-year-old leaves are only slightly higher than normal. The curves show a sharp decrease in sulphur content in the vicinity of Marble. From there to Bossburg the values are only slightly above the controls. There is evidence of a soil effect tending to increase the sulphur content of the foliage at Bossburg and Kettle Falls (Fig. 4).

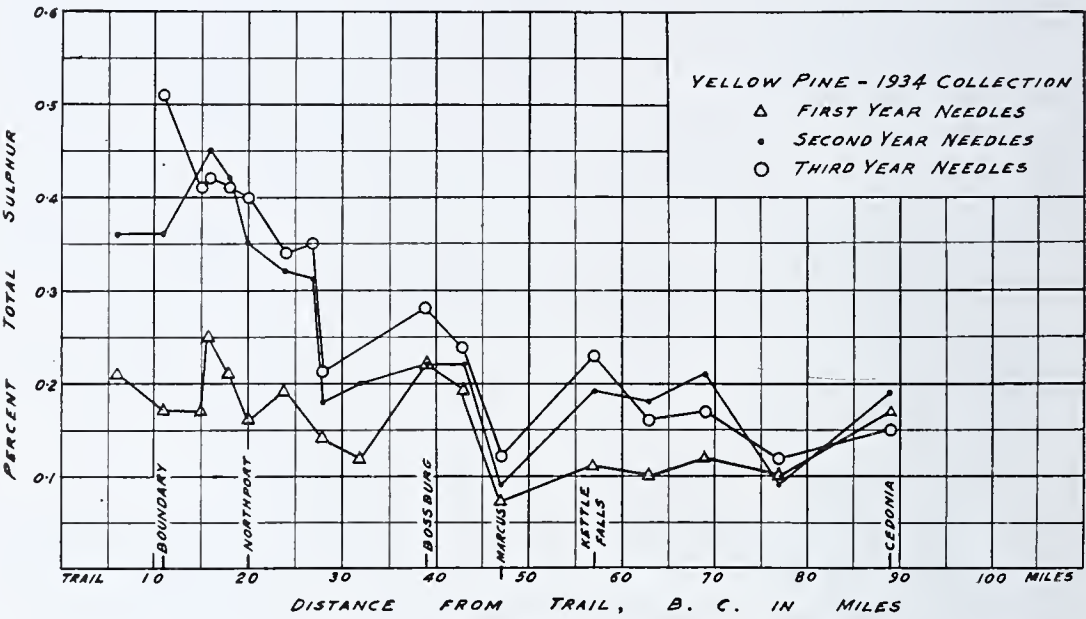


FIG. 4.—The sulphur content of vegetation in northern Stevens County, Wash.

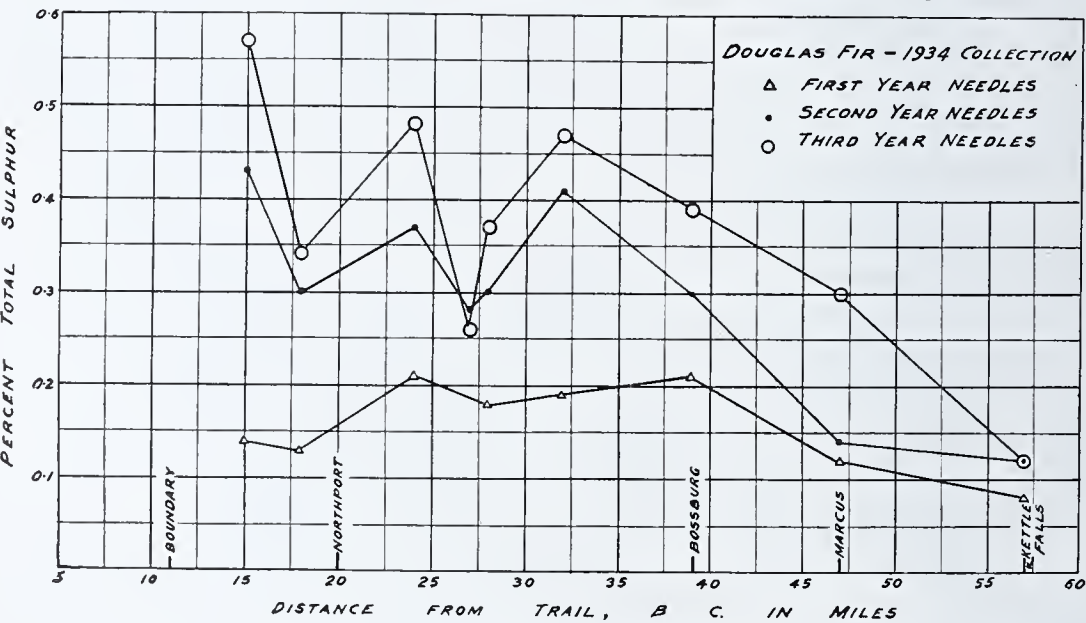


FIG. 5.—The sulphur content of vegetation in northern Stevens County, Wash.

Douglas fir, being a more sensitive indicator of sulphur dioxide occurrence than yellow pine, shows the effect of sulphur accumulation at a somewhat greater distance from Trail. The curves for the second- and third-year leaves show a definitely abnormal sulphur content as far as China Bend, a few miles south of Marble. From there on the values drop rapidly, although in the three-year-old leaves the sulphur content would appear to be somewhat higher than normal even at Marcus. The first-year leaves show only a small accumulation of sulphur even in the vicinity of Northport (Fig. 5).

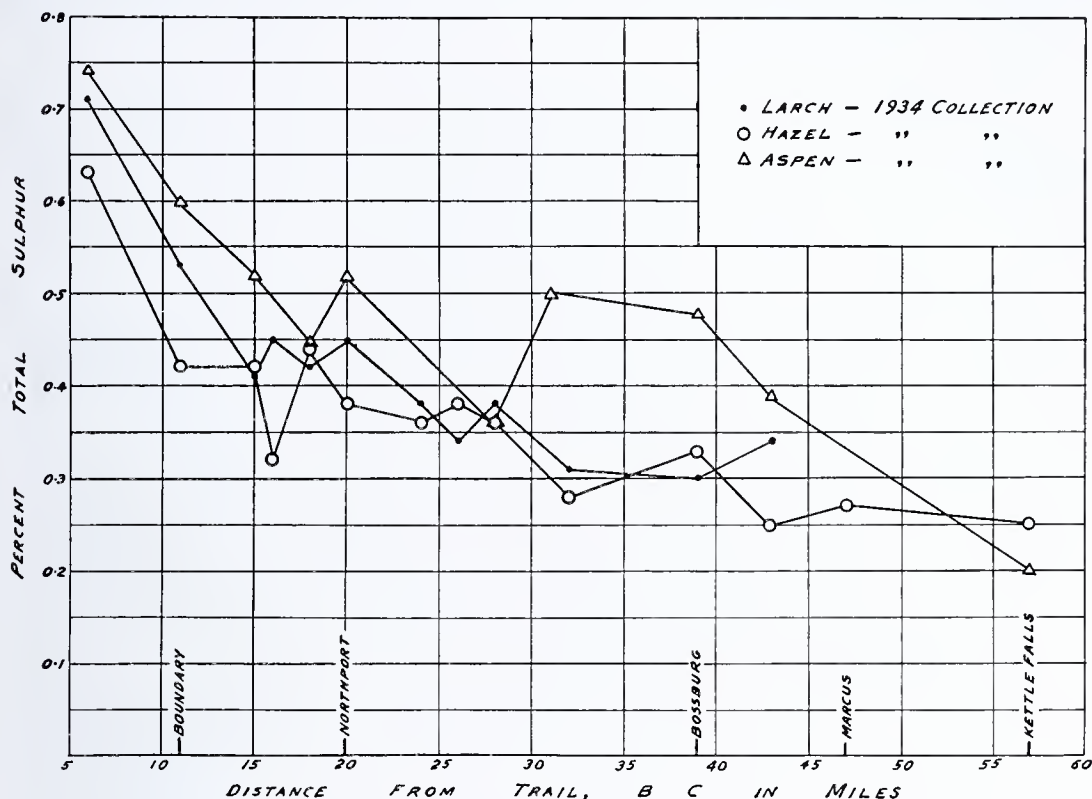


FIG. 6.—The sulphur content of vegetation in northern Stevens County, Wash.

Larch, hazel, and aspen collections (Fig. 6) show a sharp decrease in sulphur content from high values in the vicinity of Beaver Creek, about six miles down the river from Trail, to relatively lower values at a point 15 miles south of Trail. From Northport to Marble there is a further decrease. Beyond Marble there is practically no effect on the hazel and larch, but the aspen shows an increase in sulphur content at China Bend and at the mouth of Flat Creek which is maintained as far as Bossburg. From Bossburg southward the sulphur content of aspen drops rapidly. It is probable that aspen is a more sensitive indicator of the presence of sulphur dioxide than either hazel or larch. Larch, however, is more susceptible to injury in the early summer than either hazel or aspen.

With regard to the distribution of gas in the main valley of the Columbia River, the 1934 data indicate that the zone of penetration of the smoke stream has moved northward for a considerable distance to the Bossburg area since

1930. Even in that part of the Columbia valley between the Boundary and Marble there is a large decrease in the total sulphur content of the various plant species of the 1934 collections, as compared with the corresponding values of the 1930 collections. Thus the aspen and hazel collections of 1930 at a point about 18 miles from Trail show a sulphur content of 0.83% and 0.68% respectively, while the same species in 1934 collected at the same point have a sulphur content of 0.45 and 0.44% respectively. Similarly, the sulphur content of the third-year leaves of Douglas fir collected in 1930 at Marble show a sulphur content of 0.71%, whereas leaves of the same age collected in 1934 contain 0.37% sulphur.

In the tributary valleys also there was a substantial reduction in the extent of penetration of the smoke stream in 1934 compared with 1930. The foliage collections in the valley of Cedar Creek show evidence of the presence of sulphur dioxide as far as the bridge, about two and one-half miles east of the Columbia River. Collections farther up Cedar Creek show no appreciable accumulation. In Deep Creek valley there has been an appreciable effect as far as the dam about two miles from the mouth of the creek. Farther on, at a point about three miles from the mouth of the creek, there is no appreciable effect on vegetation. In the case of Sheep Creek valley, there is definite evidence of sulphur accumulation in the foliage at a point three miles from the mouth of the creek. Six miles from the mouth, beyond Velvet, the accumulation is negligible. In Onion Creek valley, about two miles from the mouth, the old leaves of fir show an accumulation of sulphur. There is no noticeable effect on the pine, and practically none on the larch, hazel, and aspen, the sulphur content of the last-named species being close to normal. In Flat Creek valley there is no evidence of the presence of sulphur dioxide in those collections which were taken on the border of the Colville Forest Reserve, about four and one-half miles from the Columbia River. The sulphur content here is not above what would be considered normal in outside areas. The foliage collections of 1934 from the tributary valleys show the same effect as that noted in the valley of the Columbia River, *i.e.*, a marked reduction in sulphur content compared with collections taken at corresponding points in 1930.

The analyses of the foliage collections made in 1935, which appear in Table VII, indicate a more extensive distribution of gas than in the preceding year. At the sulphur dioxide recorder station 15 miles south of Trail there was an increase of 35% in the total hours of positive readings during 1935 in comparison with 1934. The number of hours of readings higher than 0.25 p.p.m. was increased by 10% and that higher than 0.50 p.p.m. by 28%. In the yellow pine the sulphur content increased abnormally from year to year in the main Columbia valley as far as Bossburg, 39 miles south of the smelter. Between Bossburg and Kettle Falls the sulphur dioxide effect is slight. Evidently beyond Bossburg the sulphur dioxide concentrations were so low that yellow pine was not influenced appreciably by them.

TABLE VII
THE SULPHUR CONTENT OF DOUGLAS FIR AND YELLOW PINE
Collections made in October, 1935

Approx. distance from Trail, miles	Description of location	Total sulphur on dry basis, %						
		Yellow pine, year's leaves			Douglas fir, year's leaves			
		1935	1934	1933	1935	1934	1933	1932
Columbia River Valley								
6	Beaver Creek, B. C.	0.39	0.55	—	—	—	—	—
11	International Boundary...	0.44	0.56	0.56	—	—	—	—
15	Wood Spur	0.30	0.46	0.35	0.42	0.55	0.58	0.69
17	Big Nigger Creek	0.29	0.49	0.51	0.39	0.49	0.51	0.59
19	Mouth of Deep Creek	0.26	0.32	0.32	0.28	0.43	0.53	0.58
19	Mouth of Sheep Creek	0.26	0.36	0.39	0.27	0.38	0.45	0.46
21	Northport	0.29	0.40	0.40	0.30	0.47	0.59	0.57
25	Mouth of Onion Creek	0.24	0.38	0.44	0.30	0.45	0.51	0.58
27	Rattlesnake Creek	0.20	0.30	0.31	0.24	0.32	0.35	0.36
28	Crown Creek	0.19	0.30	0.28	0.32	0.41	0.48	0.50
32	China Bend	0.24	0.40	0.42	0.31	0.44	0.53	0.57
33	Mouth of Flat Creek	0.20	0.27	0.25	0.21	0.31	0.37	0.43
39	Bossburg	0.25	0.37	0.39	0.28	0.43	0.50	0.57
43	Evans	0.22	0.29	0.26	0.21	0.29	0.35	0.38
47	Marcus	0.23	0.29	0.27	0.33	0.46	0.49	0.53
52	Kettle Falls	0.22	0.26	0.23	0.20	0.27	0.31	0.35
Approx. distance from Columbia River	Tributary Valleys							
3	Cedar Creek— Cedar Creek bridge	—	—	—	0.23	0.30	0.36	0.42
6	Cedar Lake	—	—	—	0.24	0.30	0.33	0.36
0.3	Deep Creek— Mouth of Deep Creek	0.26	0.32	0.32	0.28	0.43	0.53	0.58
1.5	Deep Creek dam	0.21	0.28	0.23	0.22	0.28	0.33	0.37
2.5	Near Rosendahl ranch	0.19	0.23	0.21	0.21	0.29	0.35	0.40
5	Near Gus Maki ranch	0.17	0.22	0.22	0.24	0.31	0.33	0.35
10	Near Gezelius ranch	0.16	0.16	0.17	0.19	0.20	0.26	0.29
12	South end Deep Lake	0.13	0.17	0.19	0.17	0.15	0.15	0.16
0.5	Sheep Creek— Mouth of Sheep Creek	0.26	0.36	0.39	0.27	0.38	0.45	0.46
2.5	Near Murphy ranch	0.22	0.29	0.27	0.25	0.38	0.48	0.49
3.5	Near junction of Big and and Little Sheep	0.25	0.38	0.39	0.30	0.46	0.54	0.55
5	Velvet	0.18	0.24	0.29	0.24	0.32	0.38	0.41
0.2	Onion Creek— Mouth of Onion Creek	0.24	0.38	0.44	0.30	0.45	0.51	0.58
2	2 mi. up Onion Creek	0.22	0.28	0.35	0.34	0.41	0.48	0.52
5	5 mi. up Onion Creek	0.19	0.22	0.23	0.21	0.26	0.25	0.32
1.5	Big Nigger Creek— 1.5 mi. from river	0.29	0.49	0.51	0.39	0.49	0.51	0.59
4	West fork, west side Sec. 5, T. 40, R. 40, altitude 3,300 ft.	—	—	—	0.24	0.34	0.42	0.50
5	Williams Lake	0.22	0.28	0.28	0.26	0.34	0.36	0.40

The Douglas fir collections of 1935 show a continuous increase in sulphur content from the one-year-old leaves to the four-year-old leaves at all locations in the Columbia River valley between the International Boundary and Kettle Falls. They indicate the absorption of sulphur dioxide from the atmosphere for a greater distance from Trail than the yellow pine collections. Douglas fir being a more sensitive indicator of sulphur dioxide occurrence than yellow pine, even appears to absorb traces of gas such as would not be detectable in the year to year growth of yellow pine.

In the tributary valleys also there was a more extensive distribution of gas in 1935 than in 1934. In Deep Creek the yellow pine collections showed only a slight sulphur dioxide effect beyond a few miles from the Columbia River, but the Douglas fir collections showed some accumulation as far up the valley as 10 miles. Similarly, in Onion Creek valley the yellow pine collections two miles from the Columbia River indicated a definite accumulation of sulphur, but no appreciable effect at five miles. The Douglas fir leaves, on the other hand, showed a slight positive accumulation at this point.

The analyses of the foliage collections of 1936, given in Table VIII, indicate a consistently lower sulphur content than in 1935 at most points in the Columbia River valley and in the tributary valleys. This is in agreement with the sulphur dioxide recorder readings, which show that at the Stroh ranch for the six months from April to September, 1936, there was a decrease of about 12% in the total hours of gas recorded, as compared with the corresponding period of 1935. In the main valley of the Columbia River the Douglas fir leaves show evidence of an abnormal accumulation of sulphur as far as Marcus, but the yearly sulphur increment at Kettle Falls is slight. In yellow pine the values, as in 1935, indicate the influence of smelter fumes as far as the neighborhood of Bossburg. Below this point the annual sulphur increments are so small that it is doubtful whether they are due to atmospheric sulphur dioxide.

Variation in Sulphur Content of Leaves with Altitude

A comparison has been made of the sulphur content of collections of foliage in the Northport area at different elevations (see Table IX). Such collections have been made at two points:

1. In the neighborhood of Scriver Creek on a mountain about 15 miles south of the smelter.
2. In the Deep Creek valley on a mountain about two miles from the Columbia River and 18 miles south of the smelter.

In the first collection at 2,700 ft. above sea level an abnormal annual increase in sulphur content was evident, the values for 1930 and 1927 Douglas fir leaves being respectively 0.25 and 0.54%. At 4,700 ft., on the same mountain, the fir leaves in 1931 contained 0.15% sulphur in the current year's growth, and the

TABLE VIII

THE SULPHUR CONTENT OF DOUGLAS FIR AND YELLOW PINE

Collections made in October, 1936

Approx. distance from Trail, miles	Description of location	Total sulphur on dry basis, %						
		Yellow pine, year's leaves			Douglas fir, year's leaves			
		1936	1935	1934	1936	1935	1934	1933
Columbia River Valley								
6	Beaver Creek, B. C.	0.43	0.46	—	—	—	—	—
11	International Boundary ...	0.38	0.50	0.54	—	—	—	—
15	Wood Spur	0.24	0.33	0.28	0.35	0.53	0.60	0.58
17	Big Nigger Creek	0.23	0.21	0.35	0.26	0.41	0.45	0.46
19	Mouth of Deep Creek	0.20	0.21	0.25	0.32	0.45	0.47	0.50
19	Mouth of Sheep Creek	0.22	0.33	0.31	0.24	0.39	0.39	0.46
21	Northport	0.22	0.30	0.31	0.26	0.36	0.43	0.47
25	Mouth of Onion Creek	0.17	0.30	0.36	0.26	0.40	0.48	0.48
27	Rattlesnake Creek	0.18	0.20	0.25	0.19	0.28	0.33	0.28
28	Crown Creek	0.20	0.26	0.28	0.22	0.26	0.36	0.27
32	China Bend	0.23	0.34	0.38	0.29	0.42	0.46	0.51
33	Flat Creek	0.17	0.20	0.23	0.19	0.26	0.32	0.37
39	Bossburg	0.22	0.25	0.30	0.27	0.37	0.44	0.49
43	Evans	0.16	0.20	0.25	0.20	0.23	0.33	0.37
47	Marcus	0.19	0.24	0.25	0.25	0.38	0.42	0.42
52	Kettle Falls	0.18	0.21	0.23	0.16	0.21	0.25	0.29
Tributary Valleys								
3	Cedar Creek— Cedar Creek bridge	—	—	—	0.18	0.34	0.39	0.45
6	Cedar Lake	—	—	—	0.18	0.22	0.25	0.29
1.5	Deep Creek— Deep Creek dam	0.13	0.21	0.21	0.21	0.30	0.35	0.42
2.5	Near Rosendahl ranch	0.19	0.23	0.26	0.17	0.27	0.32	0.32
5	Near Maki ranch	0.15	0.18	0.20	0.23	0.27	0.26	0.27
10	Near Gezelius ranch	0.11	0.15	0.14	0.16	0.18	0.17	0.18
12	Deep Lake	0.10	0.14	0.14	0.13	0.14	0.15	0.16
2.5	Sheep Creek— Near Murphy ranch	0.18	0.23	0.26	0.22	0.36	0.44	0.48
3.5	Junction Big & Little Sheep Creek	0.22	0.26	0.30	0.26	0.41	0.45	0.44
5	Velvet	0.18	0.23	0.24	0.18	0.26	0.30	0.32
2	Onion Creek— 2 mi. up Onion Creek	0.17	0.21	0.22	0.23	0.34	0.38	0.42
5	5 mi. up Onion Creek	0.17	0.18	0.23	0.19	0.22	0.24	0.25
5	Williams Lake	—	—	—	0.26	0.32	0.38	0.40

same in that of the preceding year. Unfortunately, the 1929 and 1928 leaves of the trees in this area had been destroyed by the tussock moth and samples of these could not be obtained. However, collections of larch and ninebark leaves were obtained, and these showed sulphur contents of 0.16 and 0.14%

TABLE IX
VARIATION IN SULPHUR CONTENT OF DOUGLAS FIR AND YELLOW PINE
WITH INCREASING ALTITUDE

Elevation, ft.	Description of location	Total sulphur dry basis, %							
		Yellow pine, year's leaves				Douglas fir, year's leaves			
		1930	1929	1928	1931	1930	1929	1928	1927
Collections made during November, 1930									
	In Deep Creek valley, 18 mi. south of Trail, B. C. and about 2 mi. from Co- lumbia River valley.....								
2,000	-----	0.20	0.25	—	—	0.22	0.35	0.41	0.47
3,000	-----	0.13	0.18	0.18	—	0.16	0.27	0.36	0.40
3,750	-----	—	—	—	—	0.17	0.20	0.23	0.26
4,200	-----	—	—	—	—	0.14	0.13	0.22	0.25
Collection made September 27, 1930									
	Sriver Creek, 15 mi. south of Trail, B. C.								
2,700	Sriver Creek, on moun- tain above Stroh ranch ..	—	—	—	—	0.25	0.37	0.59	0.54
Collection made July 15, 1931									
4,700	Sriver Creek on moun- tain above Stroh ranch...	—	—	—	0.15	0.15	—	—	—
	Larch 0.16								
	Ninebark 0.14								

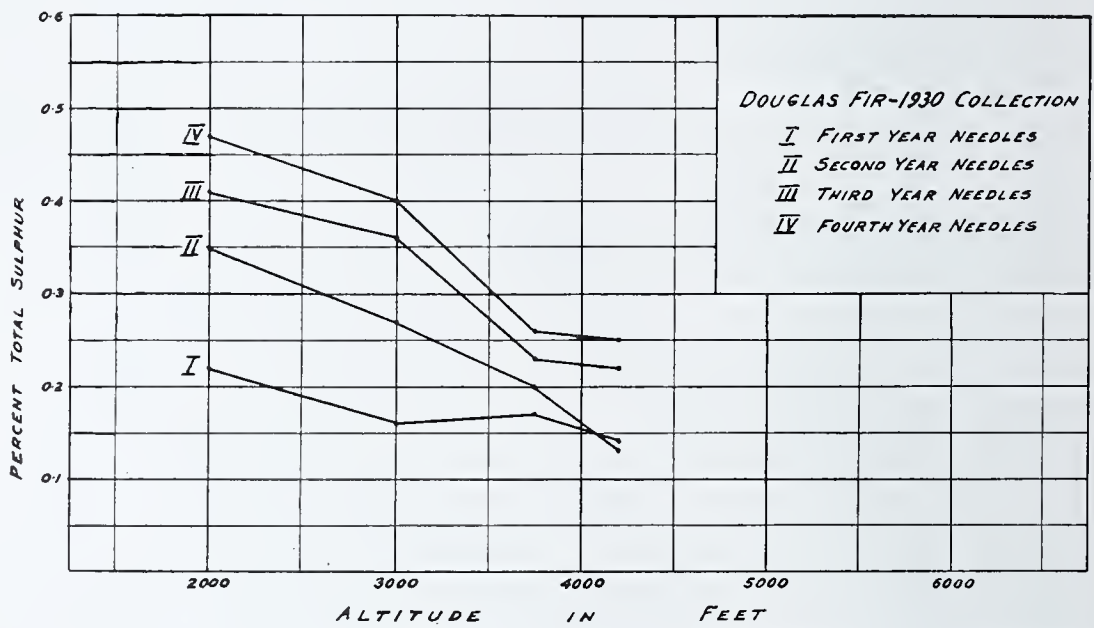


FIG. 7.—The sulphur content of Douglas fir leaves at various elevations on a mountain in the Deep Creek area of northern Stevens County, Wash.

respectively. These values are low enough to be within the normal range for these species.

The results of the Deep Creek collections, about six miles south of the International Boundary, are illustrated graphically in the curves in Fig. 7. The sulphur in fir leaves at an elevation of 2,000 ft. increased from 0.22% in the 1930 leaves to 0.47% in the 1927 leaves. At an altitude of 3,000 ft. the values for leaves of corresponding years were reduced to 0.16 and 0.40%. The rates of increase at elevations of 3,750 and 4,200 ft. were relatively insignificant.

The results indicate that the elevation above sea level reached by the smoke stream as it passes down the Columbia River valley is in the neighborhood of 3,750 ft.

Relative Rates of Absorption by Conifers during the Summer and Winter

It has been shown that relatively high amounts of sulphur are found in the leaves of trees and shrubs in the smoke zone. In the deciduous species the foliage is shed in the autumn and thus the following spring the sulphur content of the leaves is again at a low level. In the case of evergreens the leaves absorb gas from year to year, and this absorption process is cumulative. The question, therefore, arises as to whether the absorption by coniferous leaves is a continuous process throughout the year or takes place only during the growing season, as in the case of deciduous species. This question is of great importance in the Trail-Northport area in view of the fact that longer fumigations, with higher average concentrations of gas, occur during the winter months than in the growing season as shown in Chapter II.

The difference in rate of absorption during the growing season and the winter months is shown by the data in Table X on the sulphur content of leaves taken from individual trees in the Northport area near the site of the Stroh and Marble recorders. Repeated collections from a Douglas fir tree at Wood Spur, about four and one-half miles south of the International Boundary, indicate that from July to November, 1932, the 1932 leaves increased in sulphur content from 0.19 to 0.32%. From December 1, 1932, to February 25, 1933, the sulphur content of the 1932, 1931 and 1930 leaves remained substantially constant. In the case of the 1930 growth there was, if anything, a slight decrease. On May 17, 1933, the new growth was sampled and showed a sulphur content of 0.16%. This increased to 0.25% by November 8, 1933. From November 8, 1933, to March 7, 1934, the sulphur content of the 1933 growth remained constant at 0.25%, notwithstanding the presence of sulphur dioxide for relatively long periods, the total number of hours of positive readings during the period January 1 to March 1, 1934, being 810 hr. at the Stroh recorder station, and 674 at the Marble station.

The collections taken from the Douglas fir trees near the Stroh farm present similar results with regard to the increase in sulphur content during the grow-

ing season and a substantially constant state during the winter months. The same trend is shown by the analyses of the leaves taken from a fir tree near the site of the recorder at Marble.

TABLE X
SULPHUR ANALYSES ON REPEATED COLLECTIONS FROM THE SAME TREES

Location south of Trail, B.C.	Date of collection	Total sulphur on dry basis, %				
		Year's leaves				
		1933	1932	1931	1930	1929
Wood Spur 15 mi.	Douglas fir (Tree No. 1)					
	July, 1932 -----	—	0.19	0.51	0.74	0.75
	November 3, 1932 -----	—	0.32	0.53	0.72	0.75
	December 1, 1932 -----	—	0.26	0.50	0.65	0.68
	February 25, 1933 -----	—	0.29	0.50	0.60	—
	June 29, 1933 -----	0.14	0.36	0.56	0.66	—
	November 8, 1933 -----	0.25	0.39	0.58	—	—
	January 9, 1934 -----	0.26	0.38	0.57	—	—
Near Stroh ranch 16 mi.	Douglas fir (Tree No. 2)					
	January, 1932 -----	—	—	0.36	0.50	0.58
	July, 1932 -----	—	0.18	0.47	0.56	0.59
	December 1, 1932 -----	—	0.24	0.55	0.63	0.63
Near Stroh ranch 16 mi.	Douglas fir (Tree No. 3)					
	February 25, 1933 -----	—	0.20	0.38	0.45	0.50
	June 29, 1933 -----	0.10	0.23	0.39	0.45	—
	November 9, 1933 -----	0.23	0.32	0.48	0.50	—
	January 9, 1934 -----	0.22	0.33	0.45	0.52	—
Near Marble recorder 30 mi.	Douglas fir (Tree No. 4)					
	November 4, 1932 -----	—	0.18	0.33	0.43	0.53
	March, 1933 -----	—	0.18	0.31	0.39	0.46
	June 28, 1933 -----	0.11	0.26	0.34	0.43	—
	November 9, 1933 -----	0.19	0.28	0.36	0.42	—
Near Stroh ranch 16 mi.	Yellow pine (Tree No. 5)					
	January, 1932 -----	—	—	0.21	0.37	0.39
	April, 1932 -----	—	—	0.23	0.30	0.30
	November 3, 1932 -----	—	0.21	0.26	0.38	—
	March, 1933 -----	—	0.16	0.29	0.33	—
	June 29, 1933 -----	0.13	0.25	0.27	0.34	—
	November 19, 1933 -----	0.24	0.31	0.33	—	—
Near Marble recorder 30 mi.	Yellow pine (Tree No. 6)					
	April 10, 1933 -----	—	0.16	0.23	0.33	—
	June 28, 1933 -----	0.10	0.18	0.24	0.28	—
	November 9, 1933 -----	0.16	0.24	0.28	0.29	—
	March 7, 1934 -----	0.17	0.19	0.25	—	—

The newly formed leaves of the current year's growth of Douglas fir collected on May 17, 1933, contained the following sulphur content:

Wood Spur (Tree No. 1) 0.16
Near Stroh ranch (Tree No. 3) 0.13
Near Marble
recorder (Tree No. 4) 0.11

In yellow pine there is the same characteristic increase in sulphur content during the growing season. However, compared with fir, the rate of accumulation is less, and for that reason the total sulphur in such leaves does not reach values as high as those registered by the older leaves of Douglas fir. For instance, near the Stroh farm (Table X), the highest sulphur content recorded by three-year-old leaves of yellow pine is 0.39%. Similar growth on fir shows a sulphur content of 0.58 and 0.63%. From the data in Table X it is apparent that the sulphur content of yellow pine remained fairly constant or decreased slightly during these winter months.

As the question of absorption of sulphur dioxide by conifers during the winter months was one of extreme importance in connection with the general problem of injury to evergreens by smelter fumes, some further study was made of this matter during the winters of 1935-36, and 1936-37. Collections of foliage were

TABLE XI
SULPHUR ANALYSES OF WINTER COLLECTIONS OF YELLOW PINE
FROM THE SAME TREES NEAR WOOD SPUR

Tree No.	Date of collection	Total sulphur on dry basis, %		
		Year's leaves		
		1935	1934	1933
205	November 20, 1935 -----	0.28	0.45	0.40
205	March 9, 1936 -----	0.33	0.50	0.39
206	November 20, 1935 -----	0.25	0.45	0.31
206	March 9, 1936 -----	0.35	0.45	0.36
207	November 20, 1935 -----	0.23	0.36	0.36
207	March 9, 1936 -----	0.29	0.40	0.41
208	November 20, 1935 -----	0.30	0.40	0.45
208	March 9, 1936 -----	0.36	0.46	0.48
Average	November 20, 1935 -----	0.27	0.42	0.38
Average	March 9, 1936 -----	0.33	0.45	0.41
		1936		
		1935		
		1934		
205	November, 1936 -----	0.30	0.37	0.42
205	March, 1937 -----	0.33	0.37	0.44
206	November, 1936 -----	0.29	0.33	0.36
206	March, 1937 -----	0.31	0.36	0.36
207	November, 1936 -----	0.27	0.34	—
207	March, 1937 -----	0.29	0.37	—
208	November, 1936 -----	0.28	0.37	0.43
208	March, 1937 -----	0.30	0.40	0.44
Average	November, 1936 -----	0.285	0.35	0.40
Average	March, 1937 -----	0.31	0.375	0.41

made from four trees each of yellow pine and Douglas fir in November, and in the following March. The Douglas fir was located near the Stroh farm and the yellow pine near Wood Spur, these points being respectively 16 and 15 miles from the smelter at Trail. The results of the analyses of these collections are presented in Tables XI and XII. From an examination of these figures and averages it will be seen that in the case of Douglas fir the variations from November to March are so small that they may be regarded as being within the range of sampling error. The values obtained for yellow pine, however, indicate a slight but consistent increase in sulphur content in all collections.

Significance of Rate of Absorption of Sulphur Dioxide

With regard to the possible injurious effects of the accumulation of sulphur in leaves through exposure to sulphur dioxide, the rate of absorption is of much

TABLE XII
SULPHUR ANALYSES OF WINTER COLLECTIONS OF DOUGLAS FIR
FROM THE SAME TREES NEAR THE STROH RANCH

Tree No.	Date of collection	Total sulphur on dry basis, %			
		Year's leaves			
		1935	1934	1933	1932
201	November 20, 1935	0.32	0.48	0.56	0.63
201	March 9, 1936	0.35	0.52	0.63	0.63
202	November 20, 1935	0.35	0.45	0.59	0.68
202	March 9, 1936	0.32	0.43	0.54	0.66
203	November 20, 1935	0.49	0.60	0.57	—
203	March 9, 1936	0.46	0.64	0.56	—
204	November 20, 1935	0.32	0.45	0.52	0.60
204	March 9, 1936	0.38	0.55	0.56	0.61
Average	November 20, 1935	0.37	0.495	0.56	0.64
Average	March 9, 1936	0.38	0.535	0.57	0.63

		Year's leaves			
		1936	1935	1934	1933
201	November, 1936	0.32	0.53	0.58	0.58
201	March, 1937	0.34	0.56	0.57	0.53
202	November, 1936	0.32	0.48	0.55	0.56
202	March, 1937	0.33	0.44	0.49	—
203	November, 1936	0.34	0.59	0.62	0.59
203	March, 1937	0.36	0.58	0.62	—
204	November, 1936	0.31	0.51	0.57	0.60
204	March, 1937	0.32	0.53	0.59	0.60
Average	November, 1936	0.32	0.53	0.58	—
Average	March, 1937	0.345	0.53	0.57	—

greater importance than the actual amount present. Within the Trail smoke area, sulphur accumulates in the vegetation until high values are reached, many times greater than the normal. A three- or four-fold increase over the average normal content has been found to occur in vegetation in parts of the smoke area where the leaves show no symptoms of either acute or chronic injury, and there is no measurable retardation in tree growth (see Chapter VII).

The data in Table XIII illustrate the relation between rate of absorption of sulphur dioxide and injury in controlled fumigation experiments carried out at Summerland B.C. In the first three experiments with low concentrations of sulphur dioxide the sulphur content of the yellow pine leaves increased slowly over a period of many days without injury, although in some cases the ultimate increase in sulphur was far higher than in the last four experiments, where the fumigations were injurious in every instance.

TABLE XIII
RATE OF ABSORPTION OF SULPHUR DIOXIDE BY YELLOW PINE IN
FUMIGATION EXPERIMENTS

Plot No.	Sulphur dioxide treatment		Increase in total sulphur over period of treatments, %			Remarks
			Age of leaves, years			
	Average con- centration	Duration, days	1	2	3	
44	0.22	69.0	0.280	0.260	0.120	No injury
11	0.50	14.0	0.084	0.074	0.055	"
39	0.50	42.0	0.134	0.047	0.037	"
19	0.75	6.12	0.046	0.047	0.039	Severe injury
30	5.00	1.67	0.021	0.083	0.107	"
12	5.00	5.0	0.069	0.029	0.055	"
12	5.00	5.0	0.066	0.053	0.049	"

Evidently there is no relation between sulphur content and injury within the limit of tolerance of a given species for sulphur.

Discussion

Conifers have been shown to accumulate sulphur from the atmosphere rapidly in young leaves and more gradually in older leaves over a period of years. This absorption takes place for the most part during the growing season in the Trail smoke area. During the winter months of December, January and February, Douglas fir shows no significant absorption of sulphur dioxide notwithstanding the presence of gas for longer periods and in higher concentration than during the summer months. Yellow pine, on the other hand, shows a slight increase in the sulphur content of its leaves over the winter period.

The pronounced decrease in absorption during the winter is accounted for by the greatly reduced physiological activity of the leaves. According to Weaver and Mogensen (16) transpiration losses of conifers in winter are only 1/55 to 1/251 as high as those during the autumn, which in turn are lower than the

transpiration rates during the spring and summer. Furthermore, Zacharowa (18) in a study of the gaseous exchange of conifers, obtained very low values for respiration and assimilation in pine and fir during the winter, the lowest rate of carbon dioxide exchange being found from the end of December to the beginning of February.

The results of this investigation, coupled with field observations and studies of tree growth, indicate that plants may accumulate sulphur in the leaves in amounts three or four times greater than normal without injury or retardation in growth. Although plants are sensitive indicators of sulphur dioxide occurrence, there is, within relatively wide limits, no relation between sulphur content and injury.

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CHAPTER V

THE HYDROGEN ION CONCENTRATION, BASE EXCHANGE CAPACITY, AND SULPHATE CONTENT OF SOILS

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Introduction

The soils of the Trail-Northport area have been exposed to the fumes emitted by two smelters. The smelter at Trail, B.C. has been in operation since 1896. A smelter was also operated in the town of Northport, Washington, about 20 miles south of Trail, from 1896 to 1908, and from 1916 to 1921. During the first period of operation of the Northport smelter, open roasting was practised and undoubtedly caused severe damage to the vegetation in the vicinity.

The purpose of this investigation was to determine whether the fertility of the soils of this area had been appreciably affected by prolonged exposure to the action of atmospheric sulphur dioxide. This gas may be absorbed directly by the soil, may be carried into the soil with the atmospheric precipitation, or may ultimately reach the soil indirectly through absorption by the vegetation. The atmospheric sulphur dioxide conditions in this area over the period 1930-1937 have been discussed in Chapter II. A comparison of the gas records during these eight years with the data on sulphur emission given in the chart, Fig. 1, Chapter I, provides some estimate of the amount of sulphur dioxide to which the soils of this area have been exposed during the operation of the smelter at Trail. Owing to the topography of the Columbia River valley and other factors, the intensity of the sulphur dioxide visitations decreases quite rapidly with distance from the smelter to a point about 15 miles away, and from there onwards the decrease in average concentration with distance is more gradual. In addition to such amounts of sulphur as may be accumulated in the soils of this area by exposure to the sulphur dioxide in the atmosphere, somewhat less than 8 lb. of sulphur per acre is washed down annually by precipitation, according to analyses of rain water and snow samples collected in the vicinity of Northport, Washington.

Review of Literature

Wieler (15, 16) has advanced the theory that bases, especially lime, are removed from the soil by the solvent action of sulphur dioxide fumes and acids which come in contact with it. From experiments on soils in areas denuded by smelter fumes, Wieler found that the addition of lime resulted in good tree growth. He concluded, therefore, that the principal effect of acid fumes was due to decalcification of the soil. However, Albert, in a discussion of this work, takes issue with the conclusion reached by Wieler (17). Albert analyzed the soil at the site of Wieler's plot experiments on tree growth and found 0.76% to 1.0% of lead. The high sulphuric acid content of the soil rendered the lead soluble and toxic to all types of plants. The lime treatment converted the lead

into an insoluble carbonate and thus proved effective in reclaiming the soil. The amount of lime in the soil that is necessary for forest growth is extremely small, since, with a content of only 0.01 to 0.02% soluble lime, the forest growth is still normal.

Rusnov (12) found no relation between the lime content of the soil and injury to vegetation. Injury was as severe on soils containing a high amount of lime as on those containing much less. Kelley (4) investigated the acidity of some soils in the vicinity of Philadelphia where damage to crops was claimed to be due to factory smoke, but could find no relation between smoke and soil acidity.

The early literature on the effect of sulphur dioxide on soil has been reviewed critically by Haselhoff, Bredemann and Haselhoff (2). In many instances exposure to sulphur dioxide did not appreciably increase the sulphuric acid content of soils. In cultivated soils the effect of exposure on soil acidity was negligible, but in forest soils, particularly in the case of poorly buffered soils, a gradual loss of calcium and other bases was evident if they were exposed to long-continued fumigation with high concentrations of sulphur dioxide. In such cases, where the accumulation of sulphuric acid became abnormally high, activity of the micro-organisms was affected adversely and the normal decomposition of the humus interrupted. These authors reached the conclusion, however, that only in exceptional cases, where soils are subjected to long exposure to fairly high concentrations of sulphur dioxide, will soil injury be shown, and the result will be the leaching of bases, especially calcium, and increased acidity.

McCool and Mehlich (5) have recently investigated some soil characteristics in relation to distance from the industrial centres of Philadelphia, Pennsylvania, East St. Louis, Illinois, and St. Louis, Missouri. With the exception of the titratable acidity of a clay soil from the East St. Louis district and the sulphur content of a silt loam from the St. Louis area, statistical analyses of their data did not show a significant trend with distance in the characteristics of a given soil type. They conclude that soils about centres of considerable sulphur dioxide production have not been notably altered in spite of many years of exposure.

The application of gypsum to soils has been practised for centuries with marked influence on crop growth. The beneficial effect may have been due to either the sulphur or the calcium. Hart and Peterson (1) first pointed out the possible deficiency of sulphur in arable soils. They showed that the amount of sulphur removed by crops is generally about equal to, and in some cases much in excess of, the amount of phosphoric acid taken up. Thus it could be reasoned that, if phosphoric acid were a limiting factor in plant growth, as is so frequently the case, sulphur should be also. Many papers (6, 7, 8, 11) on the beneficial effects of sulphur-containing fertilizers have been published since that time. Not only is there a large uptake of sulphur by the crops, but there is also a considerable loss of sulphur in the drainage water. A certain amount of sulphur is added to the soil through natural precipitation, the amount being greater in

areas near cities and factories, but very rarely enough to make up for the losses mentioned above. In some cases there appears to be a relation between the presence of sulphates and the availability of phosphoric acid to the plant. There may also be some relation between the sulphate content and the number of micro-organisms in the soil.

Miller (6, 7) states that not only was an increase in plant growth obtained by the use of sulphur fertilizers on legumes, but there was also a beneficial effect on nodule development and nitrogen assimilation by the plant. Further, pot and field tests carried out in Oregon (11) over a period of years indicated the value of sulphur as a fertilizer on many types of soil throughout the state.

Olson and St. John (8) reported the results of a thorough investigation of the use of sulphur as a fertilizer in Washington, including in their report a very comprehensive review of the literature. Greenhouse tests, including crops grown in quartz sand and in soil, showed the beneficial effects of additional sulphur in the nutrients supplied. Tests conducted on the experimental farm showed that fertilizers containing sulphur all gave pronounced increases in yield. Throughout the eastern part of the state, the use of gypsum on alfalfa fields has resulted always in greater yields, and in higher protein content of the alfalfa.

These results on the beneficial effect of sulphur fertilization in Oregon and Washington are of particular interest, since part of the investigation to be described here was carried out on soils from the northeastern part of the state of Washington.

Topography and Soil Types in Columbia River Valley

The Columbia River flows in a narrow mountain valley from Trail, B.C. to Marcus, Washington. The width of the alluvial deposits and terraces in this valley varies from about one-half mile or less to more than three miles. At certain points the mountains rise from the valley in steep slopes. The boundaries of this valley are mountain slopes which show the effects of glacial action. In certain places the bed rock is exposed and in others it has been covered by deep deposits of river drift. Within a few miles of the valley the mountains rise on either side to elevations of from 3,000 to 4,500 ft.

The main soil types distributed within this narrow valley between Trail, B.C. and Marcus are the Springdale sands and loams, the Mission sands and loams, the Stevens loams, silt loams and limestone phase, the Marble sands, and others much less widely distributed, such as Hunters and Waterloo. Most of the above types of soil are in general well drained, comprise comparatively smooth lands, and their topography is not irregular enough to hamper farming operations. In addition to these soils, there are others, particularly in the tributary valleys of the Columbia River, such as Cedar Creek, Deep Creek and Sheep Creek, which consist of poorly drained bottom lands, with a high content of

organic matter, such as mucks and peats. In addition there are hilly and stony mountainous areas where the farm land is limited by the topography of the country.

The Springdale series of soils within the main valley of the Columbia River are found on the glacial lake and river terraces and consist of gravelly coarse sand, fine sand, coarse sandy loams, fine sandy loams, and silt loams. These soils are usually underlaid by porous sands and gravel. The Mission series are also soils of the glacial lake and river terraces and consist of sands, fine sands, loams, fine sandy loams, silts and clays. They are light yellowish-brown to greyish-brown soils, having, as a rule, a low content of organic matter and are usually free from gravel. The underlying sub-soil is generally heavier in character, and the heavy compact soils of this series have sub-soils of silt and clay texture. The soils are probably derived from sediment of glacial origin and occur on terraces above those on which the Springdale series are found.

The Stevens series of soils, consisting of loams, gravelly loams and silt loams, have a high value as agricultural farm land. These soils are dark greyish-brown, or dark brown to black, are friable in structure and have a high humus content. In general, these soils were formed through the weathering of glacial tills derived from limestone, slate and quartzite. The soils of this series constitute some of the best farm land in Stevens County.

The Marble, Hunters and Waterloo types are found only in small sections of northern Stevens County, and therefore are relatively unimportant agriculturally.

The topography of the country northward along the Columbia River valley into British Columbia, and for a number of miles beyond the Trail smelter, is very similar to that described for Stevens County, Washington, and the same soil types are encountered.

Methods of Sampling

The results of the action of sulphur dioxide on soils can be shown in at least three ways: (a) increase of sulphate content of the soil; (b) increase in the soil acidity; and (c) removal of bases, especially calcium. In order to obtain a picture of the trend in these factors in the soils along the Columbia River valley, it was thought advisable to cover this region, from a point well north of Trail southward to a point outside of the so-called "smoke zone", by sampling virgin soil of the same type at intervals. Both the Mission and Springdale types were sufficiently widely distributed within this valley to render them suitable for this purpose. However, the program decided upon involved the investigation of the soil profile down to a depth of three feet, and this method of sampling eliminated the Springdale soils, because of their gravelly nature. The Mission type was selected for showing the general trend along the Columbia River valley and, while this type is poorer than the Springdale, Waterloo or

Hunters; nevertheless, in order to bring out as completely as possible any effect on the soil which might be traceable to the operations of the Trail smelter, the poorest type is undoubtedly the best one for this purpose. Where it was desired to determine the degree of variation within a particular locality, most of the common types of soil were sampled.

The samples were selected at depths corresponding to 0-1, 1-3, 3-12, 0-5, 0-12, 12-24 and 24-36 in. at 20 different points, during the fall of 1935, and at 18 locations, during the spring of 1936. In general, wherever a set of seven samples of Mission were collected, one or more sets of four samples were taken close by corresponding to the depths 0-1, 1-3, 3-12 and 0-5 in. in order to determine the degree of variation at a particular location. In all, approximately 400 samples were collected in the fall of 1935, and about 200 in the spring of 1936.

Methods of Analysis

(a) Sulphate

The water soluble sulphate content of the soil samples was determined as follows: 100 gm. of air-dry soil was thoroughly shaken up with 500 cc. of distilled water and allowed to stand for several days; 250 cc. of the supernatant liquid was removed and filtered. If the solution was then not sufficiently clear for further analysis, it was taken to dryness on a hot plate; the residue was then taken up in hot water and filtered; after acidifying the filtrate with hydrochloric acid, the sulphates were determined as barium sulphate.

(b) Acidity

The determination of the hydrogen ion concentration of a soil is a measure of its acidity. A discussion on "Methods for determining the hydrogen ion concentration of soils" was published by Snyder of the U.S.D.A. Bureau of Chemistry and Soils, in January 1935 (14). Two general types of methods are available, colorimetric and electrometric. Colorimetric methods are not particularly good, it being frequently difficult to obtain a clear, colorless soil extract, especially with samples high in organic matter. There are four important electrometric methods, those using hydrogen, quinhydrone, antimony and glass electrodes. Snyder has little to say about the glass electrode, as it was just coming into general use at that time and had not reached the popularity it now enjoys. The use of the antimony electrode has never become widespread. The two most common methods are those involving the quinhydrone and the hydrogen electrodes. The quinhydrone method is more simple in its operation, but difficulties are encountered because of drifting of the potential, especially with poorly buffered soils. The presence of excessive amounts of manganese also interferes with results. The hydrogen method gives, on the whole, better results, but it necessitates a supply of pure hydrogen gas and a satisfactory coating of the electrode with platinum black or similar substance to absorb the gas,

and difficulties are sometimes encountered in both instances. Occasionally substances present in the solution being tested poison the electrode. For the purpose of this work it was decided to determine the pH value of all soils by both methods.

(c) *Base exchange*

One way of detecting the removal of bases from a soil is by determining to what extent the bases in the exchange complex have been replaced by hydrogen. This can be done by measuring the amount of exchangeable hydrogen and the total base exchange capacity, expressing them in milli-equivalents per 100 gm. of air-dry soil. From these can be calculated the degree of base saturation, expressed as the percentage obtained by the formula $\frac{B-A}{B} \times 100$, where B is the base exchange capacity and A represents the exchangeable hydrogen. A low base saturation value indicates a high degree of replacement of bases by hydrogen.

Methods for determining exchangeable bases in soil have been thoroughly reviewed by the Imperial Bureau of Soil Science (3). The method of Schollenberger and Dreibelbis (13), using neutral normal ammonium acetate as the displacing solution, appeared very satisfactory for our purpose, since total base exchange capacity and exchangeable hydrogen, as well as exchangeable calcium, could be determined on the same sample. The method of Parker (9), using neutral normal barium acetate, found to be satisfactory by Pierre and Scarseth (10), also proved worthy of consideration—consequently, some comparative analyses were made.

In Table I are presented the results of analyses for exchangeable hydrogen obtained by the two methods on five sets, of six samples each, of soil collected at different locations.

TABLE I

COMPARISON OF ANALYSES FOR EXCHANGEABLE HYDROGEN USING AMMONIUM ACETATE AND BARIUM ACETATE AS LEACHING SOLUTIONS

Soil depth, in.	Slocan		3 miles north of Trail		3 miles south of Trail		Pend Oreille		Murawski	
	NH ₄ OAc	Ba (OAc) ₂	NH ₄ OAc	Ba (OAc) ₂	NH ₄ OAc	Ba (OAc) ₂	NH ₄ OAc	Ba (OAc) ₂	NH ₄ OAc	Ba (OAc) ₂
0-1	3.34	4.16	14.17	11.88	16.12	16.57	6.66	6.86	24.62	22.84
1-3	2.45	3.40	5.91	6.50	6.89	7.62	2.95	3.60	5.70	6.14
3-12	1.33	1.88	4.59	5.31	4.54	4.65	1.69	1.82	2.41	2.61
0-5	1.96	2.51	9.38	8.91	9.53	9.17	3.86	3.56	7.39	7.33
0-12	1.82	2.41	5.37	6.77	6.45	6.60	2.90	3.00	4.68	5.71
12-24	0.64	0.76	0.98	1.06	1.08	0.89	1.26	1.19	1.16	1.06

It will be seen that, with few exceptions, the amounts of exchangeable hydrogen found by both methods are of approximately the same order; the use of

barium acetate in most cases tends to give slightly higher results. Probably the agreement between the methods is as close as can be expected.

In determining the total base exchange capacity where ammonium acetate is used, the absorbed ammonia is distilled into standard acid. Since the strong caustic soda which is used in the distillation may liberate some ammonia from the soil organic matter, blanks must be run using only caustic soda and untreated soil. Thus two distillations are necessary for each determination. In the application of the barium acetate method as suggested by Parker (9), the absorbed barium is removed from the soil sample by treatment with normal ammonium chloride and the absorbed ammonia is then distilled off as in the case of the ammonium acetate method. In order to avoid this distillation, two procedures were suggested: (a) removal of excess barium acetate by washing, displacement of absorbed barium by normal ammonium chloride, and determination of the barium as barium sulphate; (b) removal of excess barium acetate by washing, treatment of the washed soil with $N/50$ sulphuric acid, and titration of the acid after removal of the soil by filtration. The latter proposal was based on the assumption that the absorbed barium in the soil would react with the sulphuric acid and form insoluble barium sulphate; the decrease in the acidity of the standard acid would therefore be a measure of the absorbed barium, from which the base exchange capacity could be calculated. The first of these two modifications was tried out on five sets of six soils each, the second on only two sets of soils. In Table II are given the results for total base exchange capacity as found by the ammonium acetate method and by the two modifications of the barium acetate method.

No close agreement is here shown between the results obtained using barium acetate, Modification (b), and the results by the other methods. The results between the ammonium acetate method and the barium acetate method, Modification (a), are quite close in some cases, as with the Slocan set and the Pend Oreille set (surface inch excepted), while in most of the other cases there are differences, sometimes small, sometimes quite large. In nearly every case, however, where the differences are great, the amount of soluble sulphate present in the sample is large, *i.e.*, more than 100 p.p.m. (see Table III). To explain these results, it is suggested that in those samples showing a large amount of soluble sulphate, there is a fixation of barium, resulting in a lower displacement of this element than would be expected, with consequent low results for base exchange capacity. The amount of water-soluble sulphate, however, is not sufficient to account for the difference, and further investigation of this point was not carried out. It is believed, however, that the results by the ammonium acetate method are the more reliable ones, support for which is given by the results for percentage base saturation presented in Table III, calculated from the results in Tables I and II by the formula (given above), $\frac{B-A}{B} \times 100$. The results for water-soluble sulphates of the samples are also included for reference.

TABLE II
COMPARISON OF ANALYSES FOR BASE EXCHANGE CAPACITY USING
AMMONIUM ACETATE AND BARIUM ACETATE AS LEACHING SOLUTIONS

Soil depth, in.	Slocan			3 miles north of Trail			3 miles south of Trail			Pend Oreille		Murawski	
	NH ₄ OAc	Ba (OAc) ₂ (a)	Ba (OAc) ₂ (b)	NH ₄ OAc	Ba (OAc) ₂ (a)	Ba (OAc) ₂ (b)	NH ₄ OAc	Ba (OAc) ₂ (a)	Ba (OAc) ₂ (b)	NH ₄ OAc	Ba (OAc) ₂ (a)	NH ₄ OAc	Ba (OAc) ₂ (a)
0-1	17.64	17.24	13.74	15.52	10.76	—	16.26	—	6.60	14.92	13.76	28.29	19.72
1-3	9.22	9.10	7.34	6.91	5.17	5.82	9.83	5.82	2.79	6.21	6.65	7.11	6.32
3-12	7.15	8.64	7.67	7.23	6.51	6.47	8.99	6.47	4.09	3.84	4.10	6.25	5.90
0-5	9.68	10.21	8.93	11.19	8.04	7.11	11.60	7.11	4.60	7.46	7.26	9.34	8.07
0-12	9.34	10.15	8.79	7.53	6.51	6.40	9.86	6.40	3.81	6.52	6.67	7.59	7.34
12-24	4.66	5.40	3.98	3.28	4.05	4.26	4.20	4.26	2.08	3.02	3.28	4.08	4.24

TABLE III
COMPARISON OF RESULTS FOR PER CENT BASE SATURATION USING
AMMONIUM ACETATE AND BARIUM ACETATE AS LEACHING SOLUTIONS
(Water-soluble sulphates in p.p.m. air-dry soil are also included)

Soil depth, in.	Slocan				3 miles north of Trail				3 miles south of Trail				Pend Oreille				Murawski			
	NH ₄ OAc	Ba (OAc) ₂	SO ₄ p.p.m.		NH ₄ OAc	Ba (OAc) ₂	SO ₄ p.p.m.		NH ₄ OAc	Ba (OAc) ₂	SO ₄ p.p.m.		NH ₄ OAc	Ba (OAc) ₂	SO ₄ p.p.m.		NH ₄ OAc	Ba (OAc) ₂	SO ₄ p.p.m.	
0-1	81.1	75.9	62		8.7	-10.3	332		0.8	—	392		55.4	50.1	100		13.0	-15.9	148	
1-3	73.4	62.6	46		14.4	-25.6	160		30.0	-30.8	140		52.5	45.9	22		19.9	2.8	60	
3-12	81.5	78.2	41		36.5	18.5	143		49.5	28.1	180		56.0	55.6	28		60.4	55.7	36	
0-5	79.7	75.4	54		16.2	-10.7	173		17.8	-28.8	173		48.3	51.0	38		21.0	9.2	92	
0-12	80.6	76.3	54		28.6	-3.9	125		34.6	-3.0	170		55.6	55.0	13		38.3	22.1	82	
12-24	86.3	95.9	58		70.2	73.8	58		74.4	79.1	74		58.5	63.7	20		71.6	75.0	31	

In many cases, with the barium acetate method, negative base saturation values are obtained, that is, the amount of exchangeable hydrogen is greater than the total base exchange capacity. Since the amounts of exchangeable hydrogen by both methods were substantially the same, it was felt that the figures for base exchange capacity by the barium acetate method must be low in some cases. In no instance in this work has it been found that exchangeable hydrogen exceeded the base exchange capacity when ammonium acetate was used, though in one instance in Table III the base saturation is less than 1%.

Because of the fact that determination of base exchange capacity by the barium acetate method seemed to be unreliable in soils where high amounts of soluble sulphates were present, it was decided to accept the ammonium acetate method for this work. Details of the procedure adopted are as follows: Neutral normal ammonium acetate solution was made up according to the directions given by Schollenberger and Dreibebis (13) and adjusted to pH 7.07.

(i) *Exchangeable Bases*

A 50 gm. sample of the soil was put in a 600 cc. Pyrex beaker, 100 cc. of the ammonium acetate solution was added, the whole stirred thoroughly, covered with a watch-glass and left standing overnight. In the morning, the supernatant liquid was filtered through a 15 cm. Whatman No. 2 filter paper into a 250 cc. volumetric flask, the soil was transferred to the filter paper and leached with more of the ammonium acetate solution until the filtrate was exactly 250 cc.

(ii) *Exchangeable Hydrogen*

The filtrate was thoroughly mixed and a 100 cc. aliquot pipetted into a 150 cc. beaker. A little quinhydrone was introduced, and fifth-normal ammonium hydroxide solution added from a burette until the potentiometer reading corresponded to that for the original ammonium acetate solution. The amount of hydrogen ions neutralized by the standard ammonium hydroxide was calculated as the amount of exchangeable hydrogen in the soil sample. (The reaction of the ammonium acetate solution was checked each day and found to remain quite constant at pH 7.07.)

(iii) *Exchangeable Calcium*

The complete filtrate, including the aliquot used in determining exchangeable hydrogen, was placed in a 600 cc. Pyrex beaker, 10 cc. of concentrated nitric acid added, and the whole taken to dryness overnight on a low-heat hot plate. (In some cases, when the amount of exchangeable calcium was sufficiently great, only a 125 cc. aliquot was taken to dryness, in which case only 5 cc. of concentrated nitric acid was used.) When dry, the beaker was heated over a Bunsen burner to destroy organic matter; then the residue was

taken up in hot dilute hydrochloric acid. Dilute ammonium hydroxide was next added to precipitate any sesquioxides present, and the calcium was precipitated from the filtrate and determined in the usual way by titration with standard potassium permanganate solution.

(iv) Absorbed Ammonia

The soil on the filter paper, after leaching with the ammonium acetate solution, was washed with neutral 80% ethyl alcohol to remove any excess ammonium acetate. It was next subjected to gentle suction to remove excess alcohol, care being taken not to dry it unduly. The soil and filter paper were then transferred to a 500 cc. Kjeldahl flask, 50 cc. of 60% sodium hydroxide solution added and the ammonia distilled over into standard acid. During the distillation, considerable frothing takes place, which can be overcome by the addition of a few drops of mineral oil. Since a small amount of ammonia is formed by the action of the strong caustic soda on the organic matter of the soil, it is necessary to run a blank determination using 50 gm. of the untreated soil.

Exchangeable calcium was determined on 21 sets of seven samples. When exchangeable hydrogen and base exchange capacity only were being determined the soil sample used was 20 gm. The sample was treated overnight with 40 cc. of the ammonium acetate solution, filtered and washed until the filtrate was exactly 100 cc., and the total amount titrated for exchangeable hydrogen.

Acidity of Soils as Shown by the pH Values

The soil samples under investigation can be conveniently divided into three groups: (a) soils from the Trail area, from about 15 miles north of Trail, southward along the Columbia River to the International Boundary which is about 11 miles south of Trail; (b) soils from the Northport area, from the International Boundary southward along the Columbia River to Bossburg, about 26 miles south of the boundary or 37 miles south of Trail, and (c) soils from other areas. A map of these areas is shown in Fig. 3, page 25.

Comparative results for the pH values by the quinhydrone and the hydrogen electrode methods were available for 601 samples. In most cases there was a considerable difference between the two values. A comparison was made of the results which agreed within 0.05 pH units, and also those cases where the hydrogen values were higher or lower than the quinhydrone values by more than 0.05 units. It was found that:

(a) Between pH 3.0 and pH 4.0 out of 11 samples, all showed the hydrogen value to be below the quinhydrone value;

(b) Between pH 4.0 and pH 5.0, out of 87 samples, 85 showed the hydrogen value to be below the quinhydrone value, and two agreed within 0.05 units;

(c) Between pH 5.0 and pH 6.0, out of 260 samples, 230 showed the hydrogen value to be below the quinhydrone value, 13 agreed within 0.05 units, and in 17 cases the hydrogen value was greater;

(d) Between pH 6.0 and pH 7.0, out of 224 samples, 104 showed the hydrogen value to be below the quinhydrone value, 50 agreed within 0.05 units, and in 70 cases the hydrogen value was greater;

(e) Above pH 7.0, out of 19 cases, only one showed the hydrogen value to be below the quinhydrone value, three agreed within 0.05 units, and in 15 cases the hydrogen value was greater.

Thus it can be seen that, in the acid range, hydrogen values are usually below quinhydrone values; as neutrality is approached, the distribution is better, with a greater proportion of the results agreeing closely; and on the alkaline side, the hydrogen values are usually greater. In this report only the pH values determined by the hydrogen electrode method are presented. The average deviation of 24 duplicate determinations by this method was 0.16 pH.

(a) *Trail Area*

Sandy or gravelly soils of the Mission or Springdale types are naturally acid soils. Other types of soils in the Columbia River valley, with the exception of the Stevens limestone phase, are also generally acidic in character; the degree of acidity depending upon the composition of the soil. The pH data of soils in the Trail area between Blueberry, B.C., and the International Boundary have been grouped together in Table IV. The smelter at Trail is located roughly within the centre of this region and if the sulphur dioxide emitted from the stacks exerted any marked influence on the soil as a result of absorption and oxidation to sulphuric acid, it would be expected that the most acid soils would be found within this zone and some correlation would exist between the pH of soils and increasing distance from Trail.

The pH values given in Table IV indicate that the acidity of the Mission soil at a point 15 miles north of Trail is only what might be expected of this soil type. The soil samples taken from the location nine miles north of Trail are on the whole somewhat lower in pH, *i.e.*, more acid, at depths of 0-1 and 0-5 in. The same is true in connection with the samples seven miles north of Trail. This trend continues as one approaches the immediate vicinity of Trail. The most acid soils are found within a radius of three miles north or south of Trail.

Here the decrease in pH is quite marked in the surface inch of soil and to a lesser extent may be noted in the 0-5 in. depth. The samples in this area at lower depths than the first foot exhibit values which are not essentially different from those found in outside areas.

In the vicinity of Columbia Gardens (approximately eight miles south of Trail) the surface samples of Mission collected at five points within a radius

TABLE IV
PH OF SOILS FROM THE TRAIL AREA
(Hydrogen Electrode Method)

Soil type	Year	Depth in inches						24-36
		0-1	1-3	3-12	0-5	0-12	12-24	
Fifteen miles north of Trail								
Mission	1935	4.95	6.10	6.06	5.50	5.64	6.03	6.26
	1936	5.12	6.18	6.28	5.69	6.10	5.94	5.96
	1936	4.38	5.40	5.86	5.12	—	—	—
Nine miles north of Trail								
Mission	1935	4.13	4.89	5.64	4.94	5.35	6.57	6.53
	1936	4.40	5.07	5.68	4.81	5.52	5.52	6.07
	1936	4.17	5.15	5.36	4.80	—	—	—
Seven miles north of Trail								
Mission	1935	4.19	4.62	5.49	4.62	5.16	5.23	5.65
	1936	4.40	4.76	5.62	4.58	4.82	5.57	5.50
	1936	3.97	4.36	5.45	4.21	—	—	—
Three miles north of Trail								
Mission	1935	3.60	4.21	4.87	4.08	4.72	5.54	5.75
	1936	3.54	4.16	5.30	4.04	4.43	5.44	5.75
Three miles south of Trail								
Mission	1935	3.58	4.15	5.13	3.91	4.50	5.40	6.12
	1935	4.33	4.94	5.27	4.54	—	—	—
Springdale Mission	1935	3.75	4.91	6.38	4.75	—	—	—
	1936	3.65	4.18	5.26	4.38	4.66	5.82	6.28
	1936	3.82	4.40	5.32	4.50	—	—	—
	1935	3.67	4.22	4.96	4.24	—	—	—
Five miles south of Trail								
Mission Springdale	1935	3.81	4.15	4.71	4.52	—	—	—
	1935	4.83	5.70	6.10	6.00	—	—	—
Eight miles south of Trail								
Mission Springdale	1935	3.57	4.58	5.43	4.45	—	—	—
	1935	4.75	6.33	6.54	5.92	—	—	—
	1935	4.21	5.09	6.05	5.87	—	—	—
Mission	1935	4.32	5.30	5.85	5.30	5.55	6.13	6.30
	1935	4.51	5.22	5.87	5.46	—	—	—
	1936	4.48	5.18	5.85	4.68	5.79	6.00	6.39
	1936	3.66	5.09	6.22	4.58	—	—	—
Twelve miles south of Trail								
Springdale Mission	1935	5.93	6.08	6.31	5.92	—	—	—
	1935	5.52	6.11	6.25	5.74	6.21	6.42	6.48
	1935	4.50	5.84	6.29	5.36	—	—	—
	1935	4.71	5.81	6.20	5.30	—	—	—
	1936	4.99	6.15	6.22	5.57	5.67	5.93	5.76
	1936	4.53	5.51	5.99	5.08	—	—	—

of one and one-half miles exhibit a considerable degree of variation in pH, the extremes being 3.57 and 4.51. Practically no smoke effect is evident here in samples from the 1-3 in. profile, the soil below the surface exhibiting in general a normal degree of variation in hydrogen ion concentration.

The Springdale type of soil shows on the whole considerably higher values for hydrogen ion concentration than the Mission type at corresponding points. However, a similar picture of trend in pH is obtained with this type, the soil three miles south of Trail being distinctly acid in the surface inch but only slightly so at the depth 1-3 in. On the other hand eight miles south of Trail the samples show pH values of 4.75 and 4.21 in the surface inch while twelve miles south of Trail the pH rises to 5.93.

The pH determinations within the Trail region present therefore a similar trend either northwards or southwards from points within two and a half to three miles of Trail. In the general region 12 miles south of Trail and somewhere in the region 9 to 15 miles north of Trail the pH value of the soil becomes normal and is not essentially different from that found in other areas.

(b) Northport Area

The hydrogen ion concentrations of the soil types sampled within the Northport area from the International Boundary to the vicinity of Bossburg are shown in Table V, the results being listed in order of approximate distance by river from Trail, B.C.

A considerable number of soil samples have been collected in the region close to the International Boundary on both sides of the Columbia River. On the east side of the Columbia River the Mission type of soil was not obtainable but three samples of Springdale were collected, also one set of Marble soil and a set of Stevens. On the west side of the Columbia the Murawski area, one to two miles south of the boundary, was sampled extensively, the soil types consisting of Mission, Springdale, Stevens and Marble. The hydrogen ion concentration of the samples taken from locations on the east side of the Columbia cannot be considered below normal. The lowest pH value in this group was obtained in the surface inch Marble sample. This is a poor type of soil and normally exhibits low pH values. The Springdale and Stevens soils show pH values which are on the whole higher than those found at points farther south.

The Mission soils collected in the Murawski area exhibit a sharp contrast in pH to the Mission type near the mouth of the Pend Oreille on the Canadian side of the International Boundary. The Murawski Mission soils vary in pH from 3.41 to 4.34 in the five sets of surface-inch samples included in the 1935-36 collections. This is about a whole pH unit lower than the Mission series of samples collected at the mouth of the Pend Oreille 12 miles south of Trail (see Table IV). The pH at the depth 0-5 in. is also somewhat lower in the Murawski collection than in the former. On the other hand the Springdale soil near the

TABLE V
PH OF SOILS FROM THE NORTHPORT AREA
(Hydrogen Electrode Method)

Soil type	Year	Depth in inches						
		0-1	1-3	3-12	0-5	0-12	12-24	24-36
Thirteen miles south of Trail								
Springdale	1935	5.12	5.74	6.17	6.02	—	—	—
	1935	5.23	5.80	6.22	5.76	—	—	—
Marble	1935	4.65	5.33	5.65	5.23	—	—	—
Springdale	1935	6.07	6.12	6.15	6.02	—	—	—
Stevens	1935	6.01	6.00	6.33	6.20	—	—	—
Mission	1935	3.41	4.50	6.01	4.60	5.25	6.62	6.50
	1935	4.34	5.64	5.90	5.23	—	—	—
	1935	3.93	5.35	5.93	5.48	—	—	—
	1935	5.15	5.65	6.25	5.59	—	—	—
Stevens	1935	6.25	6.67	6.66	—	—	—	—
	1935	4.73	4.94	5.58	5.06	—	—	—
Marble	1935	4.73	4.94	5.58	5.06	—	—	—
Springdale	1935	4.88	6.29	5.85	5.47	—	—	—
Mission	1936	3.71	4.59	5.75	4.31	4.94	5.95	5.94
	1936	4.26	5.30	6.05	5.13	—	—	—
Fourteen and one-half miles south of Trail								
Mission	1935	5.32	6.32	6.36	5.87	—	—	—
	1935	4.94	5.65	5.97	5.48	—	—	—
	1935	4.96	6.63	6.52	6.03	6.31	6.58	6.57
	1935	4.57	5.15	5.37	4.99	—	—	—
	1936	6.06	6.59	6.61	6.05	6.20	6.39	6.41
	1936	4.86	5.62	6.01	5.20	—	—	—
	1935	5.46	5.45	5.74	5.38	—	—	—
Waterloo	1935	5.54	5.66	5.65	5.50	—	—	—
Sixteen and one-half miles south of Trail								
Mission	1935	6.07	5.17	5.70	5.69	—	—	—
Springdale	1935	5.60	6.12	6.21	5.87	—	—	—
Marble	1935	4.58	5.20	5.59	5.15	—	—	—
Mission	1935	5.53	6.70	6.60	6.52	—	—	—
	1935	4.85	4.65	4.89	4.87	—	—	—
Nineteen and one-half miles south of Trail								
Springdale	1935	5.03	5.14	5.62	5.20	—	—	—
Mission	1935	4.52	4.59	6.16	5.41	5.65	6.53	6.61
	1935	4.34	4.59	5.00	4.50	—	—	—
	1936	4.62	4.77	5.80	4.90	5.20	6.40	6.53
	1936	4.50	5.76	5.60	5.69	—	—	—
	1935	5.60	5.65	5.92	5.67	—	—	—
	1935	4.07	4.85	6.12	4.81	5.13	6.28	6.35
	1936	4.03	4.79	5.57	4.47	4.82	6.60	6.65
	1936	5.19	6.25	6.57	5.92	—	—	—
	1936	4.22	5.10	5.86	5.40	—	—	—

TABLE V—continued
 PH OF SOILS FROM THE NORTHPORT AREA
 (Hydrogen Electrode Method)

Soil type	Year	Depth in inches						
		0-1	1-3	3-12	0-5	0-12	12-24	24-36
Twenty-one miles south of Trail								
Stevens	1935	4.77	5.24	5.56	5.20	—	—	—
	1935	5.50	5.94	6.09	5.80	—	—	—
	1935	5.82	6.36	6.48	6.13	—	—	—
Springdale	1935	4.72	5.71	5.40	5.13	—	—	—
	1935	4.75	5.24	5.29	5.50	—	—	—
	1935	5.03	5.84	6.05	5.76	—	—	—
Mission	1935	5.71	6.54	6.48	6.69	—	—	—
	1935	4.92	5.66	6.04	5.50	—	—	—
	1935	5.31	5.58	6.21	5.82	—	—	—
	1935	5.40	6.10	6.15	5.97	—	—	—
	1935	5.34	5.68	6.00	5.63	—	—	—
Twenty-three miles south of Trail								
Mission	1935	5.42	5.38	5.50	5.40	—	—	—
	1935	4.94	5.40	5.95	5.43	5.63	6.04	6.06
	1935	5.57	5.58	5.62	5.56	—	—	—
	1936	5.51	6.48	6.45	5.94	6.07	6.28	6.68
	1936	7.06	6.39	6.37	7.04	—	—	—
	1935	5.50	6.53	6.54	6.33	6.48	6.56	6.65
	1935	4.70	5.30	6.16	5.35	—	—	—
	1936	5.54	6.35	6.54	6.02	6.24	6.61	6.50
	1936	3.97	5.10	6.30	5.73	—	—	—
Waterloo	1935	5.53	5.58	5.71	5.65	—	—	—
Hunters	1935	5.67	5.79	5.88	5.76	—	—	—
Twenty-seven miles south of Trail								
Mission	1935	4.65	6.28	6.90	6.20	—	—	—
Springdale	1935	5.78	6.66	6.46	6.18	—	—	—
Mission	1935	4.83	5.52	5.76	5.33	—	—	—
	1935	4.74	5.26	6.11	5.52	—	—	—
Hunters	1935	5.16	5.24	5.68	5.27	—	—	—
Waterloo	1935	4.72	5.82	5.90	5.22	—	—	—
Thirty-seven and one-half miles south of Trail								
Mission	1935	4.25	5.90	6.18	5.52	6.13	6.48	6.47
	1936	4.55	5.21	6.37	5.69	—	—	—
	1936	4.83	6.20	6.40	5.83	6.30	6.67	6.65
	1935	4.94	6.04	6.29	5.95	5.97	6.11	6.20
	1936	4.34	5.33	6.11	6.24	—	—	—
	1936	4.89	6.42	6.00	5.80	—	—	—

Murawski place does not exhibit a markedly low pH value in the surface inch. The same is true of the Marble sand taken from this vicinity. The pH of two sets of Murawski Stevens soils varies from 5.15 to 6.25 in the surface inch, and

from 5.65 to 6.67 in the one to 3 in. depth, although these sets were collected within 100 ft. of each other. This is an example of the extent of variation that may be encountered in the field, within even a restricted area.

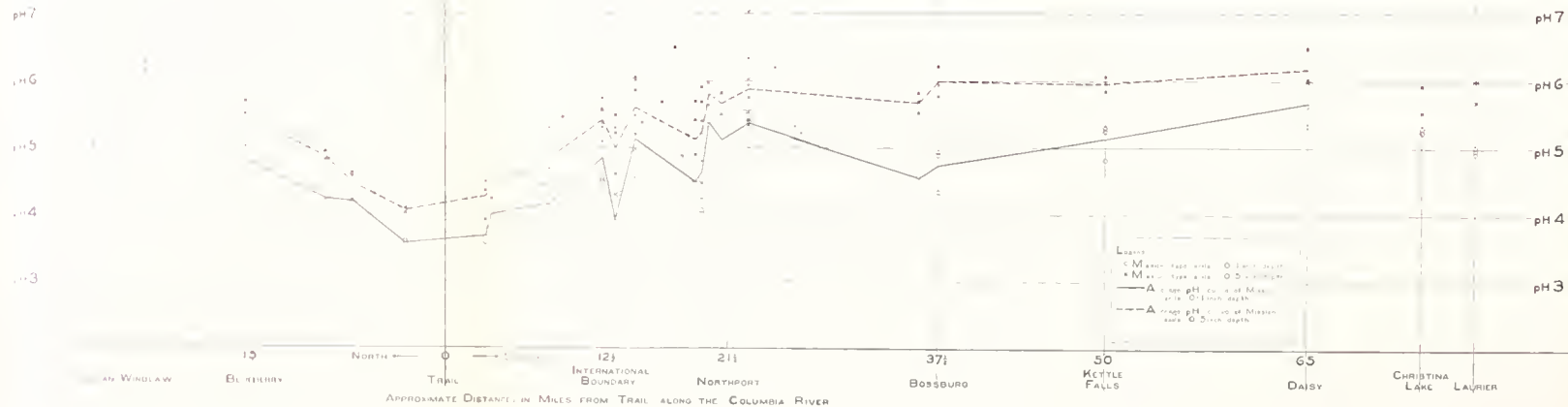
With the exception of the Murawski area none of the other Mission samples collected in the Northport area exhibits pH values in the surface inch which may be considered unduly low. The Mission soils vary considerably in hydrogen ion concentration but do not show an effect traceable to the operations of the Trail smelter such as can be shown on the soils located in Canada within a radius of about seven miles of the smelter.

Thus about three miles south of the International Boundary, east of the Columbia River, six sets of soils of the Mission type vary in pH between the extremes of 4.57 and 6.06 in the surface inch samples. A similar degree of variation exists in the 1-3 and 3-12 in. samples. The pH of the surface soil in the zone nineteen and one-half miles south of Trail is on the whole lower than in the area three miles south of the International Boundary on the east side of the Columbia River, although it is situated farther from Trail. The general trend in pH is again higher at the point twenty-one miles south of Trail (in the vicinity of Northport) and also in the Brodie Basin and Squaw Creek areas two miles farther south. The Brodie Basin area, opposite Squaw creek, illustrates to a remarkable degree the problem presented by variations in the same soil type. Thus, samples of Mission were found which vary in pH from 3.97 to 5.54 in the surface inch. In the Squaw Creek area the variation in pH in the surface samples from four sets of Mission is from 4.94 to 7.06. The general pH trend in the samples 23 miles south of Trail is considerably higher than that in the Bossburg region, although the latter is about 37 miles south of Trail by river.

The pH data for the surface inch and 0-5 in. depths have been plotted on the graphs in Figs. 1 and 2, the locations being arranged in order of increasing distance from Trail. Fig. 1 shows the pH values for all the Mission types of soil within the Trail, Northport and outside areas. Fig. 2 shows the pH values of all soil types including not only the Mission but the Springdale, Marble, Waterloo, Hunters; and Stevens as well, excepting those of the limestone phase. In each figure the curves shown are the average curves for the depths corresponding to 0-1 and 0-5 in. In the case of Fig. 1 the curves cover the Trail, Northport and other areas. In Fig. 2, however, the average curves begin at a point about three miles south of Trail, and continue only to a point 27 miles south of Trail because of the absence of soil types other than Mission in the samples collected outside this zone.

The average pH curves of the Mission soils shown in Fig. 1 indicate clearly that the soil becomes increasingly acid as one approaches Trail, beginning at a point near Blueberry, B.C., and proceeding southward. South of Trail the pH values rise rapidly from a point three miles south of Trail to the vicinity of the

FIGURE 1 pH OF MISSION SOILS



International Boundary. On the U.S. side of the International Boundary the curves show a drop in pH value or increase in acidity owing to the influence of the samples collected in the Murawski region. The pH curves then rise sharply since the next set of Mission soils collected about two miles from the boundary is quite normal. From here onwards, the pH trend may be considered normal since there is no correlation with distance from the Trail smelter. Most of the values within the Northport area are comparable with those found in other areas and in many instances soils collected in the region between Northport and the International Boundary are considerably higher in pH than those farther south in the Onion Creek and Bossburg areas.

TABLE VI
PH OF SOILS FROM OTHER AREAS
(Hydrogen Electrode Method)

Soil type	Year	Depth in inches						
		0-1	1-3	3-12	0-5	0-12	12-24	24-36
Kettle Falls, Wash.								
Mission	1935	5.30	6.21	5.88	5.98	5.98	6.33	6.41
	1936	4.81	5.64	6.27	5.84	6.24	6.55	6.52
	1936	5.24	6.33	6.31	6.05	—	—	—
Daisy, Wash.								
Mission	1935	5.35	6.28	6.23	6.01	6.08	6.41	6.63
	1936	5.89	6.83	6.95	6.00	6.63	6.66	6.58
	1936	5.66	6.63	6.80	6.52	—	—	—
Christina Lake, B.C.								
Mission	1935	5.30	6.11	6.36	5.54	5.60	6.26	6.63
	1936	5.24	6.31	6.52	5.94	5.96	6.29	6.47
Laurier, Wash.								
Mission	1935	4.99	5.96	6.15	5.70	5.78	5.80	6.08
	1936	4.92	5.93	6.12	6.07	5.99	6.38	6.52
	1936	5.23	6.12	6.41	6.03	—	—	—
Slocan, B.C.								
Mission	1935	4.64	5.23	5.27	5.02	—	—	—
Windlaw, B.C.								
Mission	1935	6.11	6.17	6.06	6.25	6.32	6.41	6.43

The curves in Fig. 2 show the trend in soil acidity of all soil types between three miles south of Trail and 27 miles south of Trail. Speaking generally, the soils in the vicinity of the Trail smelter are distinctly acid in the surface inch for a distance of about seven to eight miles south of Trail. From the vicinity of the International Boundary southwards the average pH value of the surface inch of soil is in the neighborhood of 5.0 or higher and that of the 0-5 in. depth is about 5.3 to 5.7. These values are only what might be expected of soil types such as those which are encountered within the Columbia River valley. Although time did not permit the collection and analysis of a variety of soil types in other areas, the collections of Mission soils shown in Table VI indicate the extent of variation that may be encountered in soils of this type. The extremes in pH values for the surface inch range from 4.64 to 6.11. In the depth 1-3 in. the variation is from 5.23 to 6.83 and in the 3-12 in. depth from 5.27 to 6.95. Similar extremes may be encountered within the Northport area.

Base Exchange and Degree of Saturation of Soils

The results for exchangeable hydrogen and base exchange capacity are presented in Tables VIII to XI, and the base saturation figures, calculated from these results, are given in Tables XII and XIII. The individual values for the exchangeable calcium, which were determined for about 140 samples, are not given. In most cases, however, it was found that the sum of the exchangeable hydrogen and exchangeable calcium values approximated that for base exchange capacity. A few figures presented in Table VII indicate this.

TABLE VII

THE RELATIONSHIP BETWEEN EXCHANGEABLE HYDROGEN,
EXCHANGEABLE CALCIUM, AND BASE EXCHANGE CAPACITY

Exchangeable H, m.e.	Exchangeable Ca, m.e.	Base exchange capacity, m.e.
14.17	0.40	15.52
7.92	3.08	12.33
9.31	1.62	11.57
2.28	1.55	4.26

The data presented in Tables VIII to XIII show that the base exchange capacity and exchangeable hydrogen vary considerably within a given locality, even in the same soil type. In general, the surface inch samples of soil have a higher base exchange capacity than the samples taken at lower depths in the soil profile. This is probably due to the higher percentage of organic matter present in the surface soil. The values for exchangeable hydrogen are usually higher in the surface inch samples than in those taken from the lower depths. Consequently, the degree of saturation is generally lower in the surface inch, and tends to increase in passing downward through the soil profile.

FIGURE 2

pH OF SOILS

pH 7

pH 6

pH 5

pH 4

pH 3

pH 7

pH 6

pH 5

pH 4

pH 3

- Legend
- Mission type soils 0-1 inch depth
 - × Mission type soils 0-3 inch depth
 - △ Other types 0-1 inch depth
 - Other types 0-3 inch depth
 - Average pH curve of all soils 0-1 inch depth
 - - - Average pH curve of all soils 0-3 inch depth

LOCAN WINGLAW

BLUEBERRY

TRAIL

12½
INTERNATIONAL
BOUNDARY

21½
NORTHPORT

37½
BOZSBURG

50
KEETLE
FAGLS

65
DAISY

CHRISTINA
LAKE

LAURIER

APPROXIMATE DISTANCES IN MILES FROM TRAIL ALONG THE COLUMBIA RIVER

North ← 0 → South

TABLE VIII

EXCHANGEABLE HYDROGEN OF MISSION SOILS IN THE TRAIL, NORTHPORT,
AND OTHER AREAS

(Expressed as milli-equivalents per 100 gm. air-dry soil)

Distance from Trail, miles	Depth in inches						
	0-1	1-3	3-12	0-5	0-12	12-24	24-36

Trail area

North of Trail							
15	10.80	3.34	2.65	4.81	3.53	1.28	0.54
9	7.36	6.23	2.99	5.99	3.93	0.64	0.49
7	9.48	4.54	2.39	5.81	3.18	1.76	1.13
3	14.17	5.91	4.59	9.38	5.37	0.98	0.79
South of Trail							
3	16.12	6.89	4.54	9.53	6.45	1.08	0.79
3½	12.67	6.57	4.01	6.89	—	—	—
3½	12.35	6.09	3.80	7.32	—	—	—
4½	9.72	5.79	3.77	6.37	—	—	—
7½	13.05	3.78	1.92	5.12	—	—	—
8	11.78	4.06	2.32	4.73	3.52	1.35	0.77
9	9.65	4.70	2.56	5.27	—	—	—
12	6.66	2.95	1.69	3.86	2.90	1.26	0.92
12	13.65	3.36	2.08	5.23	—	—	—
12	7.83	3.52	1.81	4.48	—	—	—

Northport area

13	24.62	5.70	2.41	7.39	4.68	1.16	1.06
13	10.96	4.92	2.46	7.86	4.65	1.66	1.39
13	11.42	3.85	2.03	5.03	—	—	—
13	13.63	4.70	2.94	6.10	—	—	—
13	12.09	4.81	2.62	5.50	—	—	—
14½	3.72	1.54	1.38	2.66	—	—	—
14½	7.92	1.74	1.59	3.04	2.32	1.11	0.68
14½	12.00	4.36	2.87	5.25	—	—	—
14½	8.87	3.45	2.02	3.84	—	—	—
15	4.89	3.16	1.60	4.25	—	—	—
16½	3.23	4.11	1.98	3.16	—	—	—
17½	6.87	1.44	1.07	1.54	—	—	—
18	9.58	4.39	2.79	4.82	—	—	—
19	15.29	5.48	3.72	5.89	—	—	—
19½	9.41	6.42	1.30	3.52	2.56	0.82	0.97
19½	6.66	3.65	1.92	2.96	—	—	—
19½	15.26	5.50	2.22	6.03	4.34	1.06	0.77
20	8.81	5.20	3.77	5.73	—	—	—
20	5.49	3.09	2.24	4.91	—	—	—

TABLE VIII—Continued

Distance from Trail, miles	Depth in inches						
	0-1	1-3	3-12	0-5	0-12	12-24	24-36
<i>Northport area</i>							
21	13.22	5.73	3.50	6.27	—	—	—
21	5.49	2.88	1.97	3.46	—	—	—
23	8.69	3.96	2.08	4.54	3.23	1.59	0.89
23	6.04	5.03	3.62	4.53	—	—	—
23	5.46	1.64	1.06	2.56	1.64	0.77	0.50
23	7.90	3.94	2.67	4.42	—	—	—
23	3.47	3.36	2.88	3.33	—	—	—
25	12.24	1.84	1.02	2.56	—	—	—
26½	9.44	3.63	2.13	5.01	—	—	—
27	15.40	5.52	1.96	4.89	—	—	—
36	9.31	2.48	1.93	3.67	2.23	0.99	0.94
37½	7.72	3.09	1.59	3.28	2.61	1.06	0.59
37½	7.84	3.30	1.86	3.04	—	—	—
<i>Other areas</i>							
Kettle Falls, Wash.	2.97	1.49	1.29	1.73	1.44	0.59	0.35
Daisy, Wash.	2.28	1.44	1.09	1.73	1.44	0.79	0.45
Laurier, Wash.	7.78	2.56	1.38	2.95	2.51	1.33	0.94
Christina Lake, B.C.	3.99	1.92	0.99	2.17	1.72	0.74	0.54
Windlaw, B.C.	3.34	2.45	1.33	1.96	1.82	0.64	0.59
Slocan, B.C.	8.93	5.24	4.28	6.96	—	—	—

In order to illustrate the extent of variation in base exchange capacity, exchangeable hydrogen and degree of saturation that may be encountered in the field in areas remote from the smoke zone, the following figures quoted from the analyses of Mission soils collected in outside areas are of interest. In the general neighborhood of Windlaw, B.C., the Mission soil is highly saturated, the figures varying from 73 to 88% in the seven samples collected from the soil profile down to a depth of three feet. The base exchange capacity in the surface inch sample is 17.64 milli-equivalents, and the exchangeable hydrogen 3.34 m.e. At the depth of 1 to 3 in. the base exchange capacity is 9.22 m.e., and exchangeable hydrogen 2.45 m.e. The base exchange values decrease with increasing depth of soil, and in the sample taken from the 12 to 24 in. profile the base exchange capacity is only 4.66 m.e., and exchangeable hydrogen 0.64 m.e. This Windlaw sample shows the highest degree of saturation of all of the Mission soils collected in outside areas. The lowest value is obtained on the samples collected in the Slocan valley about one mile south of Slocan, B.C. Here the degree of saturation is only 31% in the surface inch, and 35.7% in the depth 3 to 12 in. The base exchange capacity of the surface inch at this point is 12.94 m.e. The base exchange values of the other samples collected in areas remote from the smoke zone also show a considerable degree of variation. The percentage saturation of the surface inch samples of soil vary in the following manner: 38.4% at Chris-

tina Lake, 49.5% at Laurier, Washington, 41.3% at Kettle Falls, and 46.6% at Daisy, Wash. The highest base exchange capacity in the surface soil at these different locations is found in the Laurier sample (15.41 m.e.), and the lowest at Daisy, Wash. (4.26 m.e.).

From the data for the Mission soils collected from areas other than the Northport area, it is clear that this type of soil may vary in the degree of base saturation from about 30% to 80%, under the influence of natural conditions.

TABLE IX
BASE EXCHANGE CAPACITY OF MISSION SOILS IN THE TRAIL, NORTHPORT
AND OTHER AREAS
(Expressed as milli-equivalents per 100 gm. dry soil)

Distance from Trail, miles	Depth in inches						
	0-1	1-3	3-12	0-5	0-12	12-24	24-36
<i>Trail area</i>							
North of Trail							
15	14.68	6.41	4.00	7.17	6.91	2.99	3.42
9	10.80	11.88	8.37	10.72	8.56	4.55	3.26
7	11.97	6.71	5.75	8.30	5.92	4.07	4.76
3	15.52	6.91	7.23	11.19	7.53	3.28	3.46
South of Trail							
3	16.26	9.83	8.99	11.60	9.86	4.20	3.68
3½	13.35	7.88	7.83	8.16	—	—	—
3½	14.97	9.74	7.30	9.55	—	—	—
4½	10.55	7.33	5.76	8.25	—	—	—
7½	14.32	5.11	4.35	5.94	—	—	—
8	14.66	6.08	4.46	7.49	6.49	4.29	2.85
9	12.88	9.81	7.71	9.53	—	—	—
12	14.92	6.21	3.84	7.46	6.52	3.02	3.02
12	20.30	9.37	6.55	11.28	—	—	—
12	12.55	9.95	6.16	9.25	—	—	—
<i>Northport area</i>							
13	28.29	7.11	6.25	9.34	7.59	4.08	3.95
13	11.14	6.08	5.26	8.83	6.49	3.69	2.95
13	13.68	7.90	6.03	7.92	—	—	—
13	15.25	8.22	7.18	11.64	—	—	—

TABLE IX—Continued

Distance from Trail, miles	Depth in inches						
	0-1	1-3	3-12	0-5	0-12	12-24	24-36
<i>Northport area</i>							
13	15.20	8.39	7.85	10.06	—	—	—
14½	13.90	14.12	11.59	14.30	—	—	—
14½	12.33	5.78	4.33	5.35	5.20	2.84	2.77
14½	24.40	13.65	12.78	14.50	—	—	—
14½	14.68	7.33	4.70	7.29	—	—	—
15	14.32	10.48	8.78	12.17	—	—	—
16½	11.34	11.59	8.24	9.10	—	—	—
17½	23.00	8.04	7.15	9.05	—	—	—
18	18.46	6.81	6.57	10.10	—	—	—
19	22.65	9.06	11.20	11.34	—	—	—
19½	13.40	11.10	5.92	9.13	7.45	4.74	4.11
19½	27.40	9.57	6.94	9.05	—	—	—
19½	21.63	8.10	5.52	8.80	7.06	4.17	3.52
20	25.22	19.00	14.48	17.50	—	—	—
20	15.00	9.65	7.05	11.22	—	—	—
21	29.97	17.55	14.03	17.10	—	—	—
21	11.65	8.17	7.46	9.89	—	—	—
23	16.86	9.71	5.97	10.36	7.83	4.76	4.68
23	23.08	16.09	16.33	18.05	—	—	—
23	14.70	7.53	5.42	10.33	7.07	3.31	3.14
23	12.82	7.11	5.98	8.54	—	—	—
23	7.41	5.92	6.15	6.08	—	—	—
25	18.84	11.50	6.29	8.81	—	—	—
26½	14.70	8.70	6.37	10.10	—	—	—
27	24.65	11.65	8.30	11.53	—	—	—
36	11.57	7.15	6.49	7.20	7.48	4.20	3.87
37½	10.66	6.32	4.21	7.36	4.59	3.46	2.79
37½	10.60	5.94	5.01	6.06	—	—	—
<i>Other areas</i>							
Kettle Falls, Wash.	5.06	5.01	4.22	4.82	3.08	2.20	1.98
Daisy, Wash.	4.26	4.41	3.77	4.28	4.17	3.37	3.43
Laurier, Wash.	15.41	8.80	6.24	8.73	7.38	5.60	5.34
Christina Lake, B.C.	6.47	5.10	3.07	4.72	3.85	2.96	2.57
Windlaw, B.C.	17.64	9.22	7.15	9.68	9.34	4.66	4.91
Slocan, B.C.	12.94	7.95	6.67	10.41	—	—	—

TABLE X

EXCHANGEABLE HYDROGEN OF SOIL TYPES OTHER THAN MISSION IN THE TRAIL
AND NORTHPORT AREAS

(Expressed as milli-equivalents per 100 gm. air-dry soil)

Distance from Trail, miles	Depth in inches			
	0-1	1-3	3-12	0-5
<i>Springdale soils</i>				
In British Columbia				
2½	17.90	9.32	3.09	9.16
5½	7.01	4.80	2.66	4.05
7½	11.72	3.89	2.45	6.19
9	15.00	9.54	4.90	7.78
10½	8.26	6.30	4.75	6.93
In Washington, U.S.A.				
12½	8.00	3.46	2.34	2.97
13	5.93	3.71	2.33	4.30
13	4.07	3.75	3.56	4.04
13	10.33	3.15	2.08	4.87
16½	7.82	4.38	3.15	6.95
19	5.14	4.94	2.23	4.82
21	6.72	2.19	2.34	3.94
21	9.06	5.65	3.57	4.96
21	8.39	4.04	2.50	4.84
22	4.44	1.96	1.33	1.57
27	7.17	1.87	2.03	3.84
<i>Stevens soils</i>				
13	5.79	3.85	3.05	4.71
13	3.32	1.15	1.50	
13	3.93	3.40	1.86	2.34
20	9.16	6.24	2.82	6.40
21	3.68	2.11	1.79	2.85
21	7.17	4.99	3.35	5.20
<i>Marble soils</i>				
13	5.55	3.89	3.20	4.37
13	10.11	3.69	2.35	4.28
16½	10.49	5.24	3.48	6.15
<i>Waterloo soils</i>				
14½	6.43	6.52	4.28	6.22
23	3.92	3.14	2.00	3.12
27	15.18	3.34	2.12	5.35
<i>Hunters soils</i>				
23	4.85	2.95	2.44	3.50
27	6.94	5.88	3.56	6.60

TABLE XI

BASE EXCHANGE CAPACITY OF SOIL TYPES OTHER THAN MISSION IN THE TRAIL
AND NORTHPORT AREAS

(Expressed as milli-equivalents per 100 gm air-dry soil)

Distance from Trail, miles	Depth in inches			
	0-1	1-3	3-12	0-5
<i>Springdale soils</i>				
In British Columbia				
2½	20.95	15.34	10.88	15.48
5½	10.82	11.50	10.38	10.56
7½	18.73	14.85	11.46	17.85
9	22.40	21.05	20.05	22.63
10½	26.15	27.83	18.60	25.36
In Washington, U.S.A.				
12½	14.80	11.57	7.97	10.00
13	13.14	13.38	9.71	13.60
13	14.51	15.42	13.30	14.93
13	15.87	9.09	5.45	8.86
16½	18.90	19.00	10.90	16.37
19	9.35	9.14	6.43	9.78
21	11.12	6.55	6.42	8.30
21	14.72	10.70	9.35	11.45
21	15.20	10.91	9.20	11.37
22	15.91	12.95	10.33	13.38
27	23.53	10.37	7.80	12.62
<i>Stevens soils</i>				
13	10.36	10.26	9.52	9.08
13	13.04	11.41	11.02	
13	15.90	16.03	10.09	11.03
20	19.50	15.13	11.41	15.02
21	27.73	14.47	14.71	16.27
21	16.75	15.05	10.70	13.90
<i>Marble soils</i>				
13	7.85	8.85	8.23	9.10
13	14.09	6.03	5.07	7.21
16½	13.45	8.26	6.55	10.77
<i>Waterloo soils</i>				
14½	24.10	22.40	17.72	21.28
23	12.81	8.70	8.68	11.00
27	25.42	10.42	8.54	12.20
<i>Hunters soils</i>				
23	12.56	13.54	11.46	13.30
27	14.66	12.69	11.54	15.37

TABLE XII

BASE SATURATION OF MISSION SOILS IN THE TRAIL, NORTHPORT AND OTHER AREAS
(Expressed as per cent)

Distance from Trail, miles	Depth in inches						
	0-1	1-3	3-12	0-5	0-12	12-24	24-36
<i>Trail area</i>							
North of Trail							
15	26.4	48.0	33.7	32.9	48.9	57.3	84.2
9	31.8	47.5	64.2	44.2	54.1	86.0	84.5
7	20.8	32.3	58.3	30.0	46.4	56.8	76.3
3	8.7	14.4	36.5	16.2	28.6	70.2	77.3
South of Trail							
3	0.8	30.0	49.5	17.8	34.6	74.4	78.6
3½	5.1	16.5	48.8	15.6	—	—	—
3½	17.5	37.5	47.9	23.3	—	—	—
4½	8.0	21.0	34.6	22.8	—	—	—
7½	9.0	26.1	55.8	13.8	—	—	—
8	19.8	33.3	48.0	36.9	45.8	68.5	73.0
9	25.0	52.0	66.8	44.8	—	—	—
12	55.4	52.5	56.0	48.3	55.6	58.5	69.7
12	32.7	64.1	68.3	53.6	—	—	—
12	37.5	64.6	70.6	51.5	—	—	—
<i>Northport area</i>							
13	13.0	19.9	60.4	21.0	38.3	71.6	73.2
13	1.8	19.1	53.2	11.0	28.3	55.0	52.9
13	16.5	51.2	66.4	36.5	—	—	—
13	10.5	42.8	59.0	47.6	—	—	—
13	20.5	42.6	66.6	45.3	—	—	—
14½	73.2	89.1	88.1	81.4	—	—	—
14½	35.9	69.9	63.2	43.1	55.5	61.0	75.6
14½	50.8	68.0	77.5	63.8	—	—	—
14½	39.5	53.0	57.0	47.3	—	—	—
15	65.9	69.8	81.8	65.0	—	—	—
16½	71.5	64.5	76.0	65.3	—	—	—
17½	70.2	82.1	85.0	83.0	—	—	—
18	48.1	35.6	57.5	52.3	—	—	—
19	32.6	39.5	66.8	48.1	—	—	—
19½	29.6	42.1	78.0	61.4	65.6	82.6	76.6
19½	75.6	61.8	72.3	68.9	—	—	—
19½	29.6	32.1	59.9	31.5	38.5	74.6	78.0
20	65.1	72.6	74.0	67.3	—	—	—
20	63.4	68.0	68.2	56.3	—	—	—
21	55.9	67.4	75.0	63.3	—	—	—
21	52.9	64.7	73.6	65.0	—	—	—
23	48.5	59.3	65.3	56.3	58.7	66.5	81.0
23	73.8	68.7	77.8	74.9	—	—	—
23	62.9	78.2	80.4	75.3	76.8	76.7	84.2
23	38.4	44.6	55.3	48.2	—	—	—
23	53.2	43.3	53.2	45.2	—	—	—
25	35.0	84.0	83.8	71.0	—	—	—
26½	35.9	58.3	66.6	50.4	—	—	—
27	37.5	52.6	76.4	57.6	—	—	—
36	19.5	65.4	70.3	49.2	70.2	76.5	75.7
37½	27.5	51.1	62.3	55.5	43.1	69.3	78.8
37½	26.0	44.5	62.8	49.8	—	—	—

TABLE XII—Continued

Distance from Trail, miles	Depth in inches						
	0-1	1-3	3-12	0-5	0-12	12-24	24-36
<i>Other areas</i>							
Kettle Falls, Wash.	41.3	70.3	69.5	64.0	53.4	73.0	82.5
Daisy, Wash.	46.6	67.4	71.1	59.5	65.6	76.5	87.0
Laurier, Wash.	49.5	67.2	77.9	66.2	66.0	76.2	82.5
Christina Lake, B.C.	38.4	62.4	67.9	54.2	55.2	75.0	79.0
Windlaw, B.C.	81.1	73.4	81.5	79.7	80.6	86.3	88.0
Slocan, B.C.	31.0	34.1	35.7	33.2	—	—	—

The data on the base saturation of soils expressed as percentage show a trend similar to that of the pH determinations. The base saturation values of the Mission soils are presented in Table XII and those of the other soil types, such as Springdale, Stevens, etc., in Table XIII. The results obtained with the Mission type are shown graphically in Fig. 3, those with all soil types in Fig. 4, the ordinates representing the percentage base saturation, and the abscissae the location of the samples with respect to Trail, B.C. Two curves are shown on each of these graphs representing the average base saturation values in the surface inch and the 0 to 5 in. depth at each point where a series of samples was collected.

The average trend in base saturation of the Mission soils, shown in Fig. 3, is as follows. From a point about nine miles north of Trail, the percentage saturation of the soil for both the 0 to 1 in. and 0 to 5 in. depths decreases to a value which, within the vicinity of Trail, is lower than that shown by any of the Mission samples either in the Northport area or at points in areas removed from the smoke zone. The trend curves increase markedly in proceeding southwards from Trail to the International Boundary. Beyond the International Boundary, the only soil samples within the Northport area that can be considered abnormal are those taken from the Murawski area. All the other collections are comparable to those found in outside areas and considerably above the Mission samples collected at Bossburg as far as the surface inch is concerned. The trend shown here follows closely that described in connection with the pH curves of the Mission soils.

The surface inch samples of all types of soil show the following trend (Fig. 4) with respect to base saturation when the data are examined in order of increasing distance from Trail. About three miles south of Trail the Mission and Springdale soils exhibit the lowest values for percentage base saturation. In the general area of Columbia Gardens, B.C., the base saturation is still low, although the average of these soil types is increased considerably from the previous location. About 10½ to 12 miles south of Trail, these soil types show relatively high values for percentage base saturation.

FIGURE 3

BASE SATURATION OF MISSION SOILS

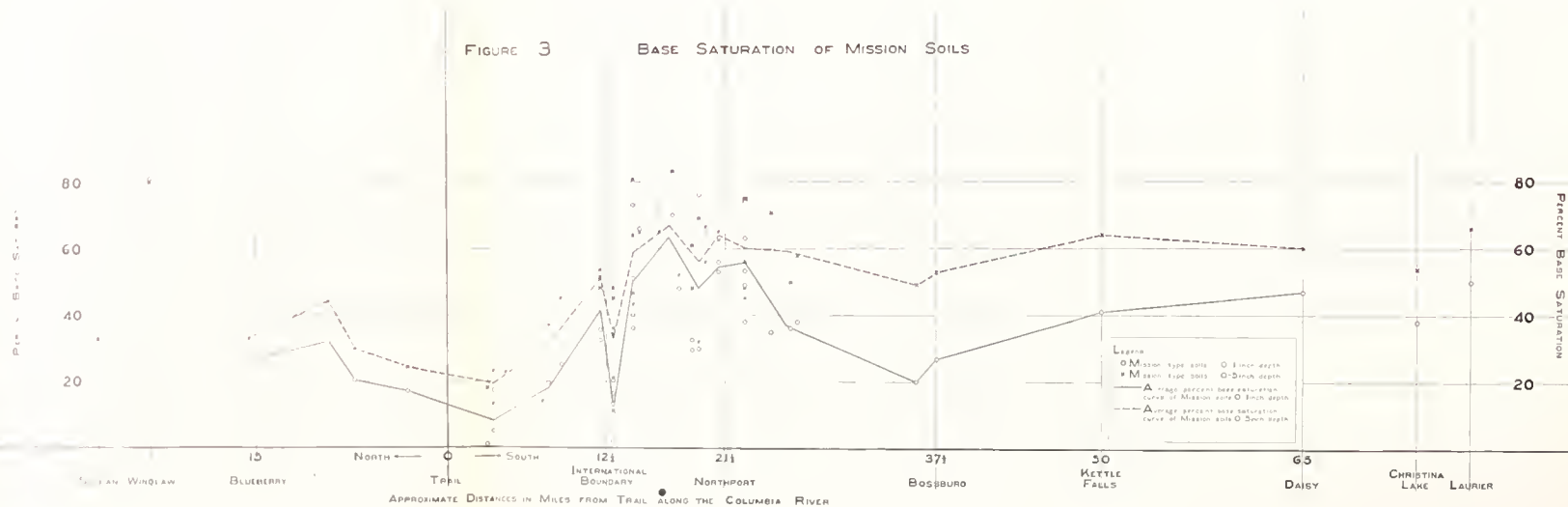


FIGURE 4 BASE SATURATION OF SOILS

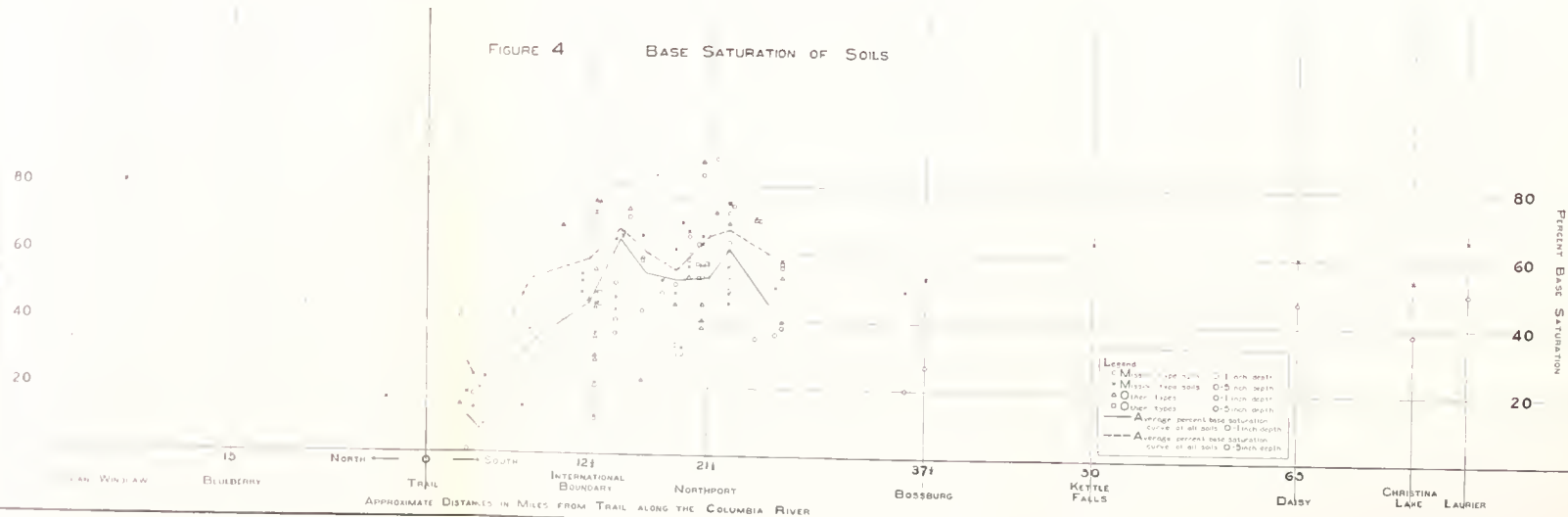


TABLE XIII

BASE SATURATION OF SOIL TYPES OTHER THAN MISSION IN THE TRAIL,
NORTHPORT AREAS
(Expressed as percentage)

Distance from Trail, miles	Depth in inches			
	0-1	1-3	3-12	0-5
<i>Springdale soils</i>				
In British Columbia				
2½	14.5	39.2	71.6	40.8
5½	35.2	58.2	74.4	61.7
7½	37.5	73.8	78.6	65.4
9	33.0	54.7	75.6	65.6
10½	68.4	77.4	74.5	72.6
In Washington, U.S.A.				
12½	46.0	70.1	70.6	70.3
13	54.9	72.3	76.0	68.4
13	72.0	75.7	73.2	73.0
13	34.8	65.3	61.8	45.1
16½	58.6	77.0	71.1	57.6
19	45.0	46.9	65.3	50.7
21	39.6	66.6	63.6	52.5
21	38.5	47.2	61.8	56.6
21	44.8	63.0	72.6	57.4
22	72.1	84.9	87.1	88.3
27	69.5	81.9	74.0	69.6
<i>Stevens soils</i>				
13	44.1	62.5	67.9	48.1
13	74.6	89.9	86.4	
13	75.3	78.8	81.5	78.8
20	53.0	58.8	75.3	57.5
21	86.7	85.4	87.8	82.5
21	57.2	66.9	68.7	62.6
<i>Marble soils</i>				
13	29.3	56.0	61.1	52.0
13	28.1	38.8	53.6	40.7
16½	22.1	36.6	46.8	42.9
<i>Waterloo soils</i>				
14½	73.3	70.9	75.5	70.8
23	69.4	63.9	77.0	71.7
27	40.4	68.0	75.2	56.1
<i>Hunters soils</i>				
23	61.4	78.2	78.7	73.7
27	52.6	53.6	69.2	57.0

On the east side of the Columbia near the boundary in Stevens County, the Mission type was not obtainable and the samples collected here represent Springdale, Marble and Stevens types. None of the soils on this side of the river are abnormal, a Springdale type about 13 miles south of Trail for example being more highly saturated with respect to exchangeable bases than the Springdale soil 21 miles south of Trail. Similarly the Stevens loam, 13 miles south of Trail is more highly saturated in the surface inch than the soil of similar type at the location 21 miles south of Trail.

The five sets of samples of Mission from the Murawski area on the west side of the Columbia near the boundary, on the other hand, are highly unsaturated, the base saturation values of the surface inch ranging from 1.8 to 20.5%. In two of the sets the soil profile at a depth of 1 to 3 in. is saturated only to the extent of 19 to 20%, while in the other samples the values range from 42 to 51%, which may be considered normal. On the other hand, the Stevens type of soil from the Murawski place does not show the abnormal condition discernible in the Mission.

The base saturation of the samples of Mission soil from 15 other points within the Northport area as far south as Bossburg exhibits a considerable degree of variation. In only a few cases do the values approach those of the Murawski Mission type.

Apart from the Murawski area the lowest base saturation values are found on the Mission soil collected about one and one-half miles north of Bossburg and at Bossburg. The degree of saturation at these two points for the surface inch samples is 19.5 and 26.0% respectively. The Bossburg area can be considered as outside the zone of any possible Trail smelter effect on soils, and in addition it has already been shown that a value as low as 31% saturation is obtained in the surface inch of Mission soil collected one mile south of Slocan, B.C.

The general trend shown in connection with the base exchange of soils is that of an abnormal condition in the vicinity of Trail, which disappears quite rapidly as one proceeds either north or south, and in the Northport area, only the Murawski samples are below the range of variation that may be considered normal. The trend in base saturation of soils is brought out quite clearly by the average curves for the surface inch of soil in Figs. 3 and 4. From a point near the International Boundary the average values exhibit fluctuations of only a minor character, and in no case can the lowest values obtained be considered abnormal. The effect falls off rapidly with increasing depth of soil, and when the 0 to 5 in. depth is considered, the soil has already reached substantially normal values for base saturation about 8 miles south of Trail.

Sulphate Content of Soils

The data on the sulphate content of all soil types in the Trail, Northport and other areas are given in Tables XIV, XV, and XVI. The results of all soil

FIGURE 5

SULPHATE CONTENT OF SOILS

SULPHATE CONTENT IN PARTS PER MILLION

600

500

400

300

200

100

- L...
 M...
 O...
 O...
 A...
 A...

WILLOW

BLUEBERRY

NORTH

TRAIL

APPROXIMATE DISTANCE

12 1/2

INTERNATIONAL BOUNDARY

21 1/2

NORTHPORT

37 1/2

BOSSBURG

50

KETTLE FALLS

63

DAISY

CHRISTINA LAKE

LAURIER

MILES FROM TRAIL ALONG THE COLUMBIA RIVER

types for the two depths 0 to 1 and 0 to 5 in. have been plotted in the graph, Fig. 5.

The sulphate content of the soils 15 miles north of Trail is of a low order, and not appreciably different from that of soils collected in other areas outside the smoke zone. Seven miles north of Trail the sulphates are noticeably higher, particularly in the 0 to 1 in. and 0 to 5 in. of soil profile. Three miles north and three miles south of Trail the sulphate content of the soil is higher in the first foot of soil profile. The second and third foot of the profiles are not any different from those found in outside areas. The sulphate content decreases rapidly beyond this point to Columbia Gardens. Here the average value for the sulphate content of all the soil types is in the neighborhood of 150 p.p.m. in the surface inch, whereas three miles south of Trail it is close to 400 p.p.m. The downward trend in sulphate content is continued to the region of the International Boundary. The sulphate content of these samples varies from less than 100 p.p.m. to about 150 p.p.m. A similar degree of variation exists elsewhere within the Northport area and there is no relation between the high or low values and distance from Trail.

The sulphate content of the soils within the Northport area is quite low, and cannot be considered as showing any measurable effect traceable to atmospheric absorption of sulphur dioxide. The average sulphate content of all the soil types (Fig. 5) shows the following trend. At Blueberry, B.C. (15 miles north of Trail) the sulphate content is low, and similar to that found in control areas outside the smoke zone. About nine miles north of Trail a slight increase is noticeable. This increase continues to within three miles of Trail. The curves indicate that within a three-mile radius of Trail, north or south, essentially similar conditions prevail with regard to the sulphate content, the top of the curves being almost flat. Beyond this zone the sulphates decrease in a manner comparable to the region north of Trail. South of the International Boundary the average sulphate values lie below 100 p.p.m., and do not differ in this respect from the soils in the control collections.

TABLE XIV
WATER SOLUBLE SULPHATES IN SOILS FROM THE TRAIL AREA
(Expressed in p.p.m. SO₄ air-dry soil)

Soil type	Year	Depth in inches						
		0-1	1-3	3-12	0-5	0-12	12-24	24-36
Fifteen miles north of Trail								
Mission	1935	62	46	41	54	54	58	64
	1936	68	60	90	71	70	75	64
	1936	92	67	91	77	—	—	—
Nine miles north of Trail								
Mission	1935	110	84	54	89	66	41	25
	1936	135	110	75	182	196	89	45
	1936	180	101	142	142	—	—	—
Seven miles north of Trail								
Mission	1935	130	96	82	104	79	82	61
	1936	269	124	147	161	149	110	132
	1936	134	115	146	135	—	—	—
Three miles north of Trail								
Mission	1935	332	160	143	173	125	58	48
	1936	422	227	89	219	139	55	55
Three miles south of Trail								
Mission	1935	392	140	180	173	170	74	60
	1935	172	80	58	80	—	—	—
Springdale	1935	420	167	118	216	—	—	—
	1936	369	274	189	161	242	76	45
Mission	1936	676	461	385	531	—	—	—
	1935	474	192	116	240	—	—	—
Five miles south of Trail								
Mission	1935	292	136	84	151	—	—	—
	1935	433	112	104	146	—	—	—
Eight miles south of Trail								
Mission	1935	148	48	35	59	—	—	—
	1935	200	83	57	82	—	—	—
Springdale	1935	250	174	156	296	—	—	—
	1935	125	66	54	66	54	59	35
Mission	1935	133	61	40	65	—	—	—
	1936	128	110	86	72	74	94	54
1936	99	81	48	86	—	—	—	
Twelve miles south of Trail								
Springdale	1935	128	80	47	95	—	—	—
	1935	100	22	28	38	13	20	16
Mission	1935	106	34	29	43	—	—	—
	1935	82	21	24	36	—	—	—
1936	98	54	33	48	72	50	48	
1936	443	96	47	152	—	—	—	

TABLE XV
WATER SOLUBLE SULPHATES IN SOILS FROM THE NORTHPORT AREA
(Expressed in p.p.m. SO_4 air-dry soil)

Soil type	Year	Depth in inches						
		0-1	1-3	3-12	0-5	0-12	12-24	24-36
Thirteen miles south of Trail								
Springdale	1935	98	36	28	100	—	—	—
	1935	78	24	19	48	—	—	—
Marble	1935	82	45	50	64	—	—	—
Springdale	1935	50	50	34	44	—	—	—
Stevens	1935	30	25	27	38	—	—	—
Mission	1935	148	60	36	92	82	31	33
	1935	111	43	49	51	—	—	—
	1935	96	67	29	64	—	—	—
Stevens	1935	74	51	29	62	—	—	—
	1935	61	65	58	—	—	—	—
Marble	1935	62	26	25	36	—	—	—
Springdale	1935	100	33	30	44	—	—	—
Mission	1936	107	92	58	96	94	60	68
	1936	166	92	69	96	—	—	—
Fourteen and one-half miles south of Trail								
Mission	1935	45	22	28	36	—	—	—
	1935	124	38	46	62	—	—	—
	1935	76	16	14	14	22	26	27
	1935	49	30	24	26	—	—	—
	1936	67	47	50	64	69	37	58
	1936	93	28	48	58	—	—	—
	1935	60	30	39	36	—	—	—
Waterloo	1935	180	40	27	36	—	—	—
Sixteen and one-half miles south of Trail								
Mission	1935	119	90	50	57	—	—	—
Springdale	1935	70	49	36	59	—	—	—
Marble	1935	58	43	34	34	—	—	—
Mission	1935	70	27	25	31	—	—	—
	1935	88	55	36	46	—	—	—
Nineteen and one-half miles south of Trail								
Springdale	1935	41	43	36	43	—	—	—
Mission	1935	91	36	28	35	21	19	37
	1935	158	55	36	83	—	—	—
	1936	59	30	28	51	43	30	33
	1936	74	65	45	59	—	—	—
	1935	65	42	34	33	—	—	—
	1935	60	43	41	53	58	26	31
	1936	45	54	67	72	70	55	35
	1936	67	73	72	58	—	—	—
	1936	66	59	37	53	—	—	—

TABLE XV—Continued

Soil type	Year	Depth in inches						
		0-1	1-3	3-12	0-5	0-12	12-24	24-36
Twenty-one miles south of Trail								
Stevens	1935	94	70	58	52	—	—	—
	1935	55	34	45	39	—	—	—
	1935	27	27	31	22	—	—	—
Springdale	1935	43	19	15	27	—	—	—
	1935	45	35	23	37	—	—	—
	1935	69	36	32	48	—	—	—
Mission	1935	84	37	26	31	—	—	—
	1935	51	37	47	38	—	—	—
	1935	57	29	17	37	—	—	—
	1935	59	37	34	54	—	—	—
	1935	31	19	17	23	—	—	—
Twenty-three miles south of Trail								
Mission	1935	92	44	37	37	—	—	—
	1935	71	22	20	30	22	14	23
	1935	55	38	38	46	—	—	—
	1936	58	36	52	45	42	86	57
	1936	54	52	58	53	—	—	—
	1935	50	23	18	25	20	25	25
	1935	23	23	23	19	—	—	—
	1936	64	62	29	53	57	52	49
	1936	63	43	54	79	—	—	—
Waterloo	1935	35	31	31	32	—	—	—
Hunters	1935	89	43	56	70	—	—	—
Twenty-seven miles south of Trail								
Mission	1935	165	36	26	103	—	—	—
Springdale	1935	74	34	26	48	—	—	—
Mission	1935	56	24	22	22	—	—	—
	1935	106	56	51	50	—	—	—
Hunters	1935	63	36	21	36	—	—	—
Waterloo	1935	41	37	37	38	—	—	—
Thirty-seven and one-half miles south of Trail								
Mission	1935	63	28	25	26	25	20	25
	1936	45	38	60	48	—	—	—
	1936	51	32	47	54	38	48	31
	1935	53	23	18	30	26	16	20
	1936	64	57	61	58	—	—	—
	1936	72	37	63	63	—	—	—

TABLE XVI
WATER SOLUBLE SULPHATES IN SOILS FROM OTHER AREAS
(Expressed in p.p.m. SO_4 air-dry soil)

Soil type	Year	Depth in inches						
		0-1	1-3	3-12	0-5	0-12	12-24	24-36
Kettle Falls, Wash.								
Mission	1935	23	15	16	19	18	18	30
	1936	54	24	44	53	41	46	44
	1936	68	54	81	54	—	—	—
Daisy, Wash.								
Mission	1935	25	14	21	23	17	20	20
	1936	51	41	24	24	31	37	22
	1936	40	30	34	35	—	—	—
Christina Lake, B.C.								
Mission	1935	20	20	26	28	33	40	35
	1936	33	38	32	25	35	26	44
Laurier, Wash.								
Mission	1935	33	26	20	31	38	28	28
	1936	76	81	77	81	74	26	21
	1936	82	68	24	85	—	—	—
Slocan, B.C.								
Mission	1935	34	22	23	21	—	—	—
Windlaw, B.C.								
Mission	1935	33	49	19	19	27	23	26

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CHAPTER VI

HYDROGEN ION CONCENTRATION AND SULPHATE CONTENT
OF WATER SUPPLIES

BY MORRIS KATZ, F. A. WYATT AND H. J. ATKINSON

Introduction

An investigation to determine whether the sulphur dioxide fumes emanating from the smelter at Trail, B.C., were affecting the sulphate content and hydrogen ion concentration of the water supplies of the area was carried out at the same time as the soil studies previously reported (Chapter V). This work involved the collection of a great number of water samples from wells, springs, creeks and lakes, not only in the immediate neighborhood of the smelter and throughout the smoke zone, but also in areas definitely outside the range of possible contamination. The areas covered by the water survey are shown in Fig. 3, Chapter II, and include the Kootenay and Slocan valleys, the Christina Lake district, the Salmon and Pend Oreille River areas, the Kettle River valley, and the district south and east of Bossburg in the neighborhood of Marcus, Colville and Chewelah, Washington.

About 350 water samples were collected in 1935 and about 200 in 1936. The sulphates were determined in the usual manner gravimetrically by precipitating as barium sulphate. The determinations were carried out on 350 cc. of water sample, any suspended matter being removed by filtering.

Since it is believed that the sulphate content of the water supplies is largely derived from the soils, unconsolidated material or parent rock through which the water has seeped, the geology of the country should be briefly reviewed. The area north of the International Boundary has been described by Daly (1), and that in the northern part of Stevens County in the state of Washington by Weaver (2).

In that section of the Columbia River valley under investigation, there are, in brief, three formations that are important: (1) igneous rocks (granites, syenites, granodiorites, etc.); (2) metamorphic sedimentary rocks, known as the "Stevens" series (quartzite, argillite, calcareous argillite, limestone and schist), the main subdivisions of this series being the Mission argillite and the Boundary argillite; (3) deposits such as gravels, sands, clays and silts of glacial and alluvial origin.

Both the sedimentary rocks and the granites may contain sulphur associated with minerals in varying amounts. Of the sedimentary rocks, the argillites are likely to contain the highest amounts of sulphur, either as sulphides or sulphates. The pure white limestone is, in general, free from sulphur, but wherever siliceous material has replaced the lime, there may be found certain amounts of lead and zinc sulphide, as well as iron and copper. Lead and zinc ores are

TABLE I

SULPHATE CONTENT OF WATER SAMPLES FROM AREAS OUTSIDE THE SMOKE ZONE

Location	Sulphates, p.p.m.	
	1935	1936
<i>Springs</i>		
Kootenay district—		
from iron mine shaft 1.5 miles north of Ainsworth	258	—
near and above iron mine 1.5 miles north of Ainsworth ..	63	—
Ainsworth Hot Springs	57	—
just east of South Slocan	60	—
Thrums spring 4.5 miles north and east of Castlegar.....	122	120
Slocan district—		
2.8 miles north of Wilson Creek	67	—
Lake Christina district—		
14.8 miles from Rossland, over the 1st summit	60	—
34.6 miles from Rossland, over the 2nd summit	83	53
between Rossland and Sheep Creek, supply for mine		
west of 1st summit	—	79
Salmon and Pend Oreille district—		
10 miles west of Salmon River, along the Pend Oreille ..	60	—
Kettle River district—		
near bridge on road up west side of Columbia River.....	58	60
South and east of Bossburg—		
east of Clugston Creek, 4 miles above Echo	52	59
west of Clugston Creek, 2.5 miles above Echo	107	105
3 miles south of Williams Lake	84	80
near road to Phelan Lake	—	81
<i>Creeks</i>		
Slocan district—		
Eight-mile Creek, 5.1 miles south of Silverton	50	—
Lake Christina district—		
on Rossland road just above the lake	97	69
Salmon and Pend Oreille district —		
7.5 miles west of Salmon River along Pend Oreille	67	—
Kettle River district—		
entering Kettle River, 7.5 miles south of Laurier	119	98
South and east of Bossburg—		
Pinkston Creek (irrigation water at farm east of Marcus)	170	182
6.5 miles north of Colville, on Marcus road	162	162
Clugston Creek, 0.5 miles above Echo	67	—
Bruce Creek, draining Phelan Lake	78	81
creek flowing east in Swede's Pass	91	58
3 miles east of Bossburg	154	104

TABLE I—Continued

SULPHATE CONTENT OF WATER SAMPLES FROM AREAS OUTSIDE THE SMOKE ZONE

Location	Sulphates, p.p.m.	
	1935	1936
<i>Lakes</i>		
Salmon and Pend Oreille district— 0.5 miles west of Customs House, Nelway -----	54	—
South and east of Bossburg— Phelan Lake -----	86	75
Williams Lake -----	93	81
<i>Wells</i>		
South and east of Bossburg— farm 1 mile south of Marcus -----	212	189

found disseminated in many places through the fracture zones of the limestone. These sulphides in exposed areas may undergo chemical weathering, with the resultant formation of sulphates. The sulphates are soluble and are therefore found in springs, creeks, lakes, etc. Because of the unequal distribution of naturally occurring sulphides and sulphates in the parent rock and unconsolidated material, it is reasonable to expect that wide variations will be found in the sulphate content of the water supplies.

Sulphate Content of Water Supplies

Water Samples from Outside Areas

In Table I are presented the results obtained from samples collected in areas outside the smoke zone. Since the purpose of collecting these samples was to show the high amount of sulphates that may occur naturally, only those samples are given which contained more than 50 p.p.m. SO_4 . Where samples were collected from the same location in both 1935 and 1936, the two values are given for comparison. While occasional high values are found in all the districts examined, there seems to be a preponderance in the area south and east of Bossburg. Here three creeks have over 100 p.p.m., with Pinkston Creek showing the highest value of 182 p.p.m. in 1936; Williams Lake contains 93 p.p.m.; and a well near Marcus, 212 p.p.m. The highest values for springs are found in the Kootenay district, one from an iron mine shaft near Ainsworth containing 258 p.p.m., and one at Thrums, 122 p.p.m.

Springs and Creeks in Trail Area

The sulphate content of the springs and creeks in the Trail area, from about 20 miles north of Trail to the International Boundary about 12 miles south of Trail, are presented in Table II, figures for both 1935 and 1936 being given wherever possible. It will be seen that there is very little, if any, difference between the 1935 and 1936 results for the springs. A greater difference is noticed in this respect in the case of the creeks, probably because the 1935 collection was made in October, after a prolonged dry spell, whereas the collection in 1936 was made in May, when a greater volume of water was flowing.

Of the springs known to arise in parent material, none has a sulphate content higher than that found for the spring at the iron mine near Ainsworth (see Table I), and only one has a value higher than that of the Thrums spring, these being the two highest values for areas outside the smoke zone. In the Columbia River valley south of the International Boundary seven of the sixteen springs known to arise in parent material showed higher values than the 161 p.p.m. found within seven miles of Trail (see Table II).

The springs arising in the sand benches south of the International Boundary in the Columbia River valley range in sulphate content from 28 p.p.m. to a maximum of 154 p.p.m., only five of the sixteen samples containing more than 100 p.p.m. (see Table III). When similar springs in the Trail area are compared with these, it will be seen that their sulphate contents are perhaps a little higher. This may indicate a slight sulphur dioxide effect in the Trail area.

The results for the creek samples indicate some increase in sulphate content in creeks near the smelter. From a point 21 miles north of Trail, most of the creeks show an increase in the concentration of sulphates as their distance from the smelter decreases. However, Murphy, Ryan and Beaver creeks are exceptions to this rule. The concentration of sulphates in these creeks is comparatively low even though they are located within five to seven miles of Trail at the points where they flow into the Columbia River.

When samples taken from the sources of some creeks in the vicinity of Trail are compared with samples taken from the same creeks near their mouths and close to the smelter, a sulphur dioxide effect is also shown. Results for Murphy Creek, Rock Creek and Stony Creek illustrate this; all contain less than 10 p.p.m. at their source but several times this in the vicinity of the smelter (93 p.p.m. in Rock Creek in the fall of 1935). Thus there is some smelter effect on the sulphate content of the creek waters in a restricted area north and south of Trail, but none is shown at a distance greater than eight miles, and some of the larger creeks even within this area show no noticeable effect.

TABLE II
SULPHATE CONTENT OF WATER SAMPLES FROM TRAIL AREA

Location	Sulphates, p.p.m.	
	1935	1936
<i>Springs arising in parent materials</i>		
15 miles north of Trail, west side of Columbia River ---	—	72
3 miles north of Trail, west side of Columbia River---	78	84
7 miles south of Trail, east side of Columbia River---	161	156
4.5 miles from mouth of Pend Oreille River -----	60	56
<i>Springs arising in sand benches</i>		
3 miles north of Trail -----	115	116
2.5 miles north of Trail, south of Rock Creek -----	202	194
2 miles north of Trail -----	186	185
3 miles north of Trail -----	186	180
near Trail, below Warfield -----	—	88
<i>Creeks</i>		
Pass Creek, 21 miles north of Trail -----	10	10
Blueberry Creek, 14 miles north of Trail -----	—	12
China Creek, 11 miles north of Trail -----	18	14
Sullivan Creek, 8 miles north of Trail -----	28	18
creek at Anderson orchard, 7 miles north of Trail -----	64	82
Murphy Creek, 5 miles north of Trail -----	29	18
Murphy Creek, at source, 13 miles west of Trail -----	7	9
creek, 4 miles north of Trail -----	106	—
Rock Creek, 3 miles north of Trail -----	93	20
Rock Creek, at source, about 13 miles west of Trail-----	—	6
Stony Creek, 2 miles from Trail -----	73	17
Stony Creek, at source -----	5	5
Mill Creek, 3 miles west of Trail -----	71	47
Cemetery Creek, 6 miles west of Trail -----	74	59
Ryan Creek, south edge of Trail -----	—	29
Smith Creek, 1.25 miles south of Trail -----	—	60
small creek, 1.5 miles south of Trail -----	—	78
Campbell Creek, 2.5 miles south of Trail -----	—	78
Bear Creek, 3 miles south of Trail -----	—	27
creek, 6 miles south of Trail -----	40	42
Beaver Creek, 7 miles south of Trail -----	27	14
creek, 7 miles south of Trail, opposite Beaver Creek -----	—	47
small creek, near Columbia Gardens, 7 miles south of Trail -----	—	59
small creek, 8 miles south of Trail -----	—	87

Springs and Creeks in the Northport Area

The sulphate contents of the water samples collected from the springs and creeks of the Northport area are presented in Tables III and IV. The locations are arranged approximately in order of their increasing distance from the Trail

smelter, being grouped according to their position on the east or west side of the Columbia River, and the springs are further subdivided into those arising in parent material and those arising in sand benches. A glance at these tables will show that there is no relation between the sulphate content of the samples and their location with respect to Trail. Some relation can be shown between the sulphate content of the water supplies and the parent material. Thus on the west side of the Columbia River, the high sulphate springs at 12, 19 and 21 miles south of Trail (253, 129 and 196 p.p.m., respectively), arise out of the Mission argillite, while the high sulphate springs on the east side of the Columbia River, located at 14 to 16 miles south of Trail (233, 170, 143 and 322 p.p.m., respectively), arise in the Boundary argillite formation. The spring at 27 miles showing 276 p.p.m. sulphate, was observed to be clearly influenced by marly-shale material, which naturally contains sulphates. On the other hand, a spring at 23 miles, with only 15 p.p.m., comes out of the mountain side from pure limestone. The variation in the sulphate content of the springs arising in sand benches has already been discussed in a comparison with similar springs in the Trail area. The results for the creek waters indicate that here also the sulphate content is influenced by the type of formation through which the creeks flow.

It is reasonable to expect that the sulphate content of creek waters would be generally higher in the fall, if the volume of flow is low, than in the spring, wherever these waters are not unduly influenced by sulphates from the parent material. On the other hand, the quantity of sulphates in creeks running through formations high in sulphur should not be materially affected by the volume of water. The results in Table IV show that in some cases there is practically no difference between the spring and fall sampling, and in others the samples collected during the spring contain a slightly smaller quantity of sulphates, but in no case is there such a big difference as was shown in some of the creeks in the Trail vicinity (Table II, Rock Creek and Stony Creek), where a smoke effect was indicated. The creek opposite Bossburg, for example, located about 37 miles from Trail, has practically the same amount of sulphates in both the spring and the fall. Incidentally the high value of 197 p.p.m. shown by this creek is by far the highest of all in the area, though this creek is farthest from the smelter.

The influence of parent material is also shown when the sulphate contents of branches of the same creek are compared. This is most noticeable in the case of Cedar Creek, the east fork having a concentration of only 16 p.p.m. in 1935 and 23 p.p.m. in 1936, whereas the west fork had a concentration of 97 p.p.m. in 1935 and 118 p.p.m. in 1936. The west fork is probably influenced by the sulphate content of the water from Cedar Lake (149 p.p.m., Table V), and also by seepage through Boundary argillite.

TABLE III

SULPHATE CONTENT OF SPRINGS IN THE NORTHPORT AREA

Location	Miles south of Trail	Sulphates, p.p.m.	
		1935	1936
<i>Springs arising in parent material</i>			
West side of Columbia River—			
farm water supply -----	12	253	269
farm water supply -----	19	129	50
farm water supply -----	21	196	195
farm water supply -----	22	73	—
north of road to Pepoon Lake -----	27	73	75
East side of Columbia River —			
Tom Bush, near source -----	14	104	107
small mine in Tom Bush Creek -----	14	233	367
Limestone Creek, at source -----	15	98	—
farm water supply -----	15	170	159
farm water supply -----	15.5	143	123
farm water supply -----	15.5	322	320
Scriver Creek, near source -----	16	32	—
farm in Brodie Basin, coming from limestone	23	15	24
from open field in Brodie Basin -----	23	88	85
up side road from Onion Creek road -----	27	276	221
near Brodie Mountain school -----	27	—	203
<i>Springs arising in sand benches</i>			
West side of Columbia River—			
south of Little Nigger, near old mill-house -----	14	73	77
half-mile south of above -----	14.5	71	66
on Columbia River bank, between the			
Nigger Creeks -----	15	55	—
between Sheep and Nigger Creeks -----	18	154	166
water supply for old placer mine -----	18	152	144
on north bank of Sheep Creek, near mouth -----	19	103	101
on Columbia River bank -----	18.5	58	65
East side of Columbia River—			
on river bank just south of boundary -----	13	151	139
on river bank -----	14.5	126	125
farm water supply -----	18.5	78	72
farm water supply -----	18.5	28	30
farm water supply -----	19	29	31
farm water supply -----	19	33	33
iron spring -----	19	38	42
farm water supply -----	19	40	51
near mouth of Deep Creek -----	19	30	34

TABLE IV
SULPHATE CONTENT OF CREEKS IN THE NORTHPORT AREA

Location	Miles south of Trail	Sulphates, p.p.m.	
		1935, fall	1936, spring
West side of Columbia River—			
Little Nigger Creek, 1 mile west of Murawski	13	46	—
Little Nigger below Murawski	13	66	39
Big Nigger Creek, west branch	16	35	—
Big Nigger Creek, east branch	16	38	—
Big Nigger Creek, just below junction of branches	16	45	—
Big Nigger Creek at main road	17	56	29
Big Nigger Creek at mouth	18	42	—
Sheep Creek at bridge near mouth	19	17	7
Sheep Creek, 2 miles from mouth	21	16	—
Sheep Creek, 4 miles from mouth	23	32	—
Squaw Creek, north branch	23	96	62
Squaw Creek, south branch	23	132	64
Squaw Creek, near mouth	23	133	75
Crown Creek at river road	28	81	76
Flat Creek at river road	30	61	66
Fifteen Mile Creek at river road	33.5	73	32
creek 5 miles north of old Bossburg ferry....	34	109	91
creek opposite Bossburg, near ferry	39	197	191
East side of the Columbia River—			
Cedar Creek, east fork	13	16	23
Cedar Creek, west fork	13	97	118
Tom Bush Creek at road	14	113	99
Limestone Creek at road	15	136	113
Scriver Creek at Stroh orchard	16	87	64
Deep Creek at mouth	19	25	19
Brodie Creek at highway	23	86	83
Onion Creek at highway	25	35	21
Ryan Creek at highway	29.5	107	154

Lakes and Wells in the Columbia River Valley

The data for lakes and wells are presented in Table V. They show that no relation exists between sulphate content and location with respect to the smelter. The two lakes within 10 miles of the smelter show the lowest values, whereas Ansaldo Lake, 35 miles from Trail, has by far the highest value. Incidentally a sample of marl taken beneath the wet peat near this lake at a depth of 12 to 16 in. contained over 600 p.p.m. of sulphates. With reference to the wells, the sulphate content fluctuates between wide limits, and the only major influence is that of the parent material through which the water has seeped. There is no relation between the sulphate values and distance from Trail.

TABLE V

SULPHATE CONTENT OF LAKES AND WELLS IN THE COLUMBIA RIVER VALLEY

Location	Miles from Trail	Sulphates, p.p.m.	
		Fall 1935	Spring 1936
<i>Lakes</i>			
Violin Lake -----	2	19	26
Rossland Reservoir -----	6	24	19
Cedar Lake -----	15	149	121
Deep Lake -----	19	23	25
Hughes Lake -----	20	253	205
Pepoon Lake -----	27	90	81
Ansaldo Lake -----	35	432	304
<i>Wells</i>			
Near International Boundary -----	12	147	100
Near Limestone Creek -----	14	182	163
Near Limestone Creek -----	14	199	—
Near Scriver Creek -----	15	246	251
Near Scriver Creek -----	15	85	115
Near Scriver Creek -----	15	151	136
Near Nigger Creek -----	17	43	45
Near Nigger Creek -----	17	142	206
Near Sheep Creek -----	18.5	50	—
Four miles from mouth of Deep Creek -----	22	31	37
Near Northport -----	22	93	84
Five miles from mouth of Deep Creek -----	23	173	140
Near Marcus, Wash. -----	46	212	189

Hydrogen Ion Concentration of Water Supplies

The hydrogen ion concentration was determined colorimetrically on 338 of the water samples taken in 1935. In only five instances (listed below) was the pH of the water below 7.0 and a pH of 6.6 was the lowest value obtained.

Location	pH
Spring 3 miles north of Trail	6.6
Sullivan Creek, 7.7 miles north of Trail	6.8
Murphy Creek, near source, 7 miles north of Rossland, B.C.	6.9
Near Tom Bush Creek, 14 miles south of Trail	6.8
Spring on mountain above Lake Christina	6.6

The remaining samples yielded pH values between 7.0 and 8.6; this indicates that free sulphurous or sulphuric acid was not present. These results agree well with the hypothesis that the sulphates found in the water supplies are in general derived from the parent material through which the water has seeped.

References

1. DALY, R. A. Memoir No. 38, on the North American Cordillera, 49th parallel, Part I, 1912.
2. WEAVER, CHARLES E. The Mineral Resources of Stevens County. Wash. Geol. Survey Bull. 20, 1920.

CHAPTER VII

THE EFFECT OF SULPHUR DIOXIDE ON THE DIAMETER
INCREMENT OF CONIFERS

BY F. E. LATHE AND A. W. McCALLUM

Introduction

General Forest Conditions in the Area Investigated

The area covered by the study of diameter increment of conifers includes a small district on the Canadian side of the International Boundary in British Columbia, the zone in which damage claims were made against the smelting company and also districts in the State of Washington well outside that in which smoke injury was regarded as possible. The general topography of the district has been described in Chapter II.

In respect to forests, this area may be divided into two parts, the first including the benches and lower slopes adjacent to the Columbia River, and the second the higher levels in the main valley and tributary valleys. The first is mainly a yellow pine area, although some Douglas fir, larch and lodgepole pine are also found here. The soil consists of sand and sandy loams, a fact which, in conjunction with the limited precipitation, renders this area fairly typical but not ideal for yellow pine, which is the most important commercial species. The Douglas fir is generally of poor quality, and is used chiefly for ties and fuel, as is also the larch. At the higher levels Douglas fir is of better quality, on account of the heavier soil and probably also a higher precipitation.

In this area, broad-leaved trees are scattered and of little or no commercial importance, and the investigation was consequently limited to the growth of conifers. Of these the following species are found in the northern part of Stevens County. They are listed approximately in the order of their importance.

Western yellow pine	<i>Pinus ponderosa</i>
Douglas fir	<i>Pseudotsuga taxifolia</i>
Western larch	<i>Larix occidentalis</i>
Western white pine	<i>Pinus monticola</i>
Western red cedar	<i>Thuja plicata</i>
Grand fir	<i>Abies grandis</i>
Engelmann spruce	<i>Picea Engelmanni</i>
Lodgepole pine	<i>Pinus contorta</i>
Juniper	<i>Juniperus scopulorum</i>

In the vicinity of Northport, the chief town in the area, most of the commercial timber has been logged off, except at the higher levels. At least 18 sawmills have within recent years been in operation in the district, but of these,

15 had closed down prior to 1930, the available timber having been cut. As a consequence of the logging operations, the remaining timber occurs almost entirely in scattered stands.

Following logging, with its resultant debris of slash, repeated fires occurred throughout practically the whole of the area, particularly in the years 1921, 1924, 1926 and 1929. As a result, it is difficult to find anywhere in this district stands of timber completely free from fire injury, and many trees, particularly those less than two or three inches in diameter, have been killed. In addition to this serious effect upon reproduction, there is an important secondary effect, in that fires have destroyed the natural seed bed of surface humus, permitting increased evaporation and making conditions less favorable for germination and growth.

During the period covered by the investigation many stands of Douglas fir in northern Stevens County were largely or completely defoliated by tussock moths. Bark beetles have been epidemic locally in such species as Douglas fir, grand fir and lodgepole pine, many scattered mature trees and saplings having been killed by these insects. Aphids, by feeding upon the needles, have been responsible for the thin foliage of many conifers.

Factors Affecting Tree Growth

The annual growth rings of trees constitute a permanent and reasonably accurate record of the reaction of the trees to their environmental conditions. Young and vigorous trees growing under uniformly favorable conditions have wide rings, with only minor variations in width from year to year. Ordinarily, however, a limit on growth in any particular year is set by some unfavorable factor or factors, and such an influence may be so great that a single dominant factor will govern tree growth over a considerable period, in which case the effect of other factors is largely or completely masked.

Water supply, including both precipitation and ground water, probably exerts a greater influence on tree growth in general than does any other factor, and in semi-arid regions precipitation is usually dominant to such a degree that practically all the trees in a given area show similar variations in diameter increment from year to year. Advantage of this fact has been taken by Douglass (2) and associates of the Carnegie Institution of Washington to carry out elaborate studies of climatic cycles extending over many centuries.

The quality of the soil is one of the most obvious factors affecting tree growth. Being relatively constant in character, it is rarely responsible for annual variations, although it may fix a limit that growth cannot exceed even with favorable precipitation and other conditions. Injury may be caused to individual trees or to forests extending over fairly large areas by such factors as fire, wind, hail, sleet, fungous and other diseases, mistletoe, the attack of insects, destruction of bark by rodents, etc. Decreased growth may even result from natural influences, such as exceptionally heavy seed production (8). Growth is frequently limited

to some degree by the density of the stand of timber, but this is unlikely to cause marked variations from year to year. When density is substantially reduced by extensive logging operations, there may be a sudden and pronounced increase in the growth rate.

Upon other detrimental factors there are sometimes imposed fumigations with industrial gases, which, in sufficient concentration, may be of a definitely toxic character. When such effects are small, the problem of distinguishing clearly between the reduction in annual increment due to atmospheric pollution and that caused by other influences becomes difficult.

It may be noted, however, that industrial gases are not necessarily harmful to vegetation. They nearly always contain a substantial proportion of carbon dioxide, a factor definitely favorable to plant growth. Even sulphur dioxide in the atmosphere may conceivably be beneficial when below toxic concentrations, particularly if the soil of the fumigated area is deficient in sulphates. Factors affecting tree growth have been discussed at length by various investigators (1, 8, 9).

Previous Investigations

A comprehensive investigation of the effect of industrial gases upon tree growth was carried out in 1892 by Reuss (10) in Upper Silesia, Germany, in a forest reserve of mixed spruce and pine, covering about 7,500 acres, and also in a second forest of 1,835 acres. Fifty-four industrial plants, with a total yearly output of about 35,000 metric tons of sulphur dioxide, were located within a radius of six kilometres. Two borings were made at breast height on 10 trees in each of 35 out of 64 sections of this forest, and in each section one or two trees were cut to determine their age and as a check on the borings.

The trees selected for study included only those spruces of about equal age (80 to 120 years), height, diameter and vigor, and in every case an effort was made to exclude trees that had been affected by any accelerating or retarding factor other than fumes. The degree of injury was estimated by calculating the percentage variation from the normal annual growth, as derived from Burckhardt's Tables of normal forest yields for spruce. These tables were tested on 34 trees in an unaffected area. The whole forest was found to be damaged to some extent, and all damage was ascribed to sulphur dioxide. No constant relation was found to exist between the sulphur dioxide content of the atmosphere and retardation of growth, the latter depending to a large extent upon the individual powers of resistance of the tree and its age. In most cases, the amount of sulphur dioxide absorbed by the needles was considered negligible at distances of more than seven kilometres.

Gerlach (4) studied the loss of wood due to smoke injury and concluded that spruce suffered considerably. Eicke (3) investigated the diameter and height growth of pine and found that a tree 52 years old had been adversely affected

when young but later recovered to almost the same diameter and height as those of the standards set by Herwig (7). Trees 22 and 25 years of age showed much greater retardation. The need of further work was stressed.

Haselhoff and Lindau (6) discussed the effect of sulphur dioxide on the diameter increment of conifers and presented figures of cross sections of pine and spruce, both affected and unaffected by smelter fumes. The differences were ascribed to the action of sulphur dioxide, although the possibility that drought or insect injury might have affected growth was recognized.

Toumey (11) described the effect of smoke, ash and fumes from industrial plants on conifers in a narrow Connecticut valley with wooded slopes. The consumption of coal and output of zinc, copper and other metals greatly increased during the war of 1914-1918, and an examination of the valley showed that conifers were gradually disappearing and being replaced by the more resistant hardwoods. Increment borings were made in a number of localities, and while no measurements were presented it was estimated that growth had been reduced from 25 to 50%. Damage was ascribed chiefly to sulphur dioxide and zinc sulphate.

Investigation of Conditions in Stevens County

Scope of the Investigation

Studies were carried out in 1929, 1930, 1934 and 1936. In selecting the species to be used in the 1929 investigation it was decided to concentrate on yellow pine and Douglas fir, partly because they are the most important commercial species occurring in this region, and partly because they are two of the species most susceptible to sulphur dioxide injury. Lodgepole pine was also studied to some extent because of the fact that there are fairly extensive young stands of this species between Northport and the International Boundary, in the immediate valley of the Columbia River. (See general map of the area, Chapter II.) Since yellow pine grew mostly on the river benches and Douglas fir on the mountain slopes, it was decided to use the former to ascertain how far damage had occurred down the Columbia River, and the latter to determine the lateral limits. Of the three species 3,588 trees were bored for a study of diameter increment.

The 1929 studies having shown that the growth of trees in the main Columbia valley and at the mouths of its tributaries near the Boundary had been substantially affected by sulphur dioxide from Trail, and claims having been made for damages over an unexpectedly large area, the studies of 1930 were extended laterally. Control groups of Douglas fir were also selected farther outside the smoke area, in order that they might be less open to criticism. The total of Douglas fir and yellow pine bored in that year was 2,530.

By 1934 substantial reduction had been made in the amount of sulphur dioxide emitted at Trail, and a study was therefore carried out to determine what re-

covery, if any, had been made by trees injured by sulphur dioxide in previous years. The number of Douglas fir and yellow pine bored in 1934 was 2,935. The results indicated that yellow pine had made a complete recovery in all cases, but that the recovery of some of the Douglas fir growing near the Boundary was incomplete.

Atmospheric conditions following 1934 continued to improve and a final study of Douglas fir was made in 1936, when 990 trees were bored. It was considered unnecessary to do any further work on yellow pine, the condition of which was normal in 1934. In the four years 10,043 trees were bored and more than 175,000 measurements were made on the cores.

Selection of Trees

When it is desired to determine the effect of any factor upon tree growth by comparing the diameter increment of affected trees with that of trees growing under conditions free from the adverse factor, it is obviously of fundamental importance to insure that the trees to be compared have not been differently affected by other factors than that which it is desired to measure. Three different methods of selection have been used by different investigators.

Reuss (10) took only dominant trees of a character which, outside the affected area, gave a yield corresponding to that called for by Burckhardt's Tables, and assumed that in the smoke area dominant trees would, but for the effect of sulphur dioxide fumes, have shown an equal growth. In this case there are possibilities of error through mistaken judgment on the part of the individual who selects the trees and also through variations in conditions within and without the area under investigation.

A second method is that used by the United States investigators in the Trail smelter case. A census was first made of the trees at numerous points within and without the smoke area, and these were classified as good, fair, and poor, the percentage being calculated in each case. Subsequently, these percentages were used in determining the number and character of the trees to be cut or bored for measurement of diameter increment in any zone of injury or in a control area. The Tribunal was also informed that precautions had been taken to see that all groups of trees were growing under completely comparable conditions as to soil, water supply, density of stand, etc., and that in no case was any group used in which evidences of fire could be found. The success of this method of selection is obviously dependent entirely upon the judgment of the investigator.

The Canadian investigators decided to eliminate as far as possible the exercise of personal judgment. They were not able to secure enough groups of trees free from evidences of fire, and in the 1929 investigation recorded the fact that fires had occurred in recent years in 51 out of the 52 groups of trees studied. They did, however, reject any trees definitely fire-scarred, or so damaged by

insects, lightning or other cause as to be obviously unsuitable for comparison. Having done so, no further selection of trees was made according to their condition, all living trees of medium diameter being bored without distinction, until the requisite number for a particular location had been taken. Very large and very small trees were not bored. It was believed that in this way there would be secured the most accurate sample of the trees in any particular area and that, while the absolute growth in different districts might vary considerably, the trend of growth over a period of years would be comparable, except for the effect of sulphur dioxide. Observed differences in trends could then be ascribed to the action of this factor. The accuracy of sampling will be discussed later. (See p. 203 and Fig. 25.)

Size of Groups Required

Much of the work of the research staff of the Carnegie Institution of Washington, in cross-dating and in the study of climatic cycles, has of necessity been carried out on single trees from any one district. According to Glock (5) a group of five to ten specimens commonly gives ample information about a given locality. In the work of these authorities, however, sections of trees were usually made at several points, and ring growth was measured at several radii. When only one radius is measured, the number of trees must be increased in order to mask individual variations.

In the 1929 investigation, several groups of 25 trees or less were measured as single units but the variations between these, even in adjoining areas, were such as to suggest the necessity of using larger groups. Consequently, in 1930 and subsequent years it was decided to use groups of not less than 100 trees, when these were available, and the results obtained were in general much more satisfactory.

Boring of Trees and Measurement of Rings

The trees were bored on the south side at waist height with Pressler increment borers. For each tree the diameter at breast height was recorded. A record was also kept of the general character of the plot, the species growing upon it, the density of the stand, nature of the soil and any unusual condition observed.

In 1929 the measurement of the cores was carried out by the Dominion Forest Service and in subsequent years by the staff of the National Research Council. The procedure followed was to examine the cores under low-power magnification, shaving off a smooth surface in most cases, and to measure each from the outside, recording to the nearest 0.01 in. the total width from the bark rather than the width of single rings, in order to forestall the possibility of any cumulative error. Borings containing knots and fire scars and those deviating appreciably from a radial direction were discarded. In every case, measurements were

carried back at least to 1916, in order to cover the period of high output of sulphur dioxide at Trail and also that of the operation of a small smelter at Northport, which was active from 1916 to the spring of 1921. The measurements for a whole group of trees were averaged for each year, and the results plotted. When several groups relatively near one another showed almost identical form, the average figures for ring growth were plotted in a single chart to represent that area.

Precipitation and Ring Growth

The normal annual precipitation in Stevens County ranges from about 12 to 16 in. but it may on occasion rise to 20 in. or more, and may fall to 10 in. This part of the State of Washington should therefore be classified as semi-arid, and the first step in the interpretation of measurements of diameter increment was accordingly to determine what correlation, if any, obtained between tree growth and precipitation. In considering precipitation the total annual fall of rain and snow is not necessarily of greatest interest; the distribution of precipitation is at least equally important. For this reason a comparison was made in 1929 between growth and monthly precipitation, and it was found that the best correlation over the period 1915 to 1929 was obtained when the precipitation for the eight months January to August was taken into consideration. This is an indication that, in the area under consideration, winter snows melting in the spring as well as rain falling in the growing season have a favorable effect on tree growth, but that rain in the period September to December following the growing season disappears too soon to affect appreciably the tree growth of the succeeding year. This is not necessarily true in all types of soil.

In Fig. 1 is shown the average growth of 400 Douglas fir controls situated on the Kettle River, at the points indicated on the accompanying map as Groups 1 and 2 of 1936, and the average precipitation at Laurier, Colville and Kettle Falls, Washington. These towns are shown on the general map in Chapter II. The correlation between precipitation and tree growth is reasonably close, although there are minor variations for 1916, 1920, 1926 and 1936 that cannot be explained. Possibly some of these irregularities could be accounted for if the distribution of precipitation during the growing season were known, or if the precipitation at the actual point where the trees were growing had been used; unfortunately, no meteorological records are kept at these points. It is of interest to note the evidence that the adverse effect of the extremely dry summer of 1929 was carried over to 1930, and that favorable precipitation immediately preceding 1928 and 1933 led to a slightly increased growth in those years. That these are not mere coincidences is suggested by the fact that in the case of yellow pine standards for 1929 and 1934 similar observations hold for 1926, 1930 and 1933 (see Fig. 8).

A rather remarkable instance of correlation between diameter increment and precipitation is shown in Fig. 2, which represents the growth of 194 yellow pine

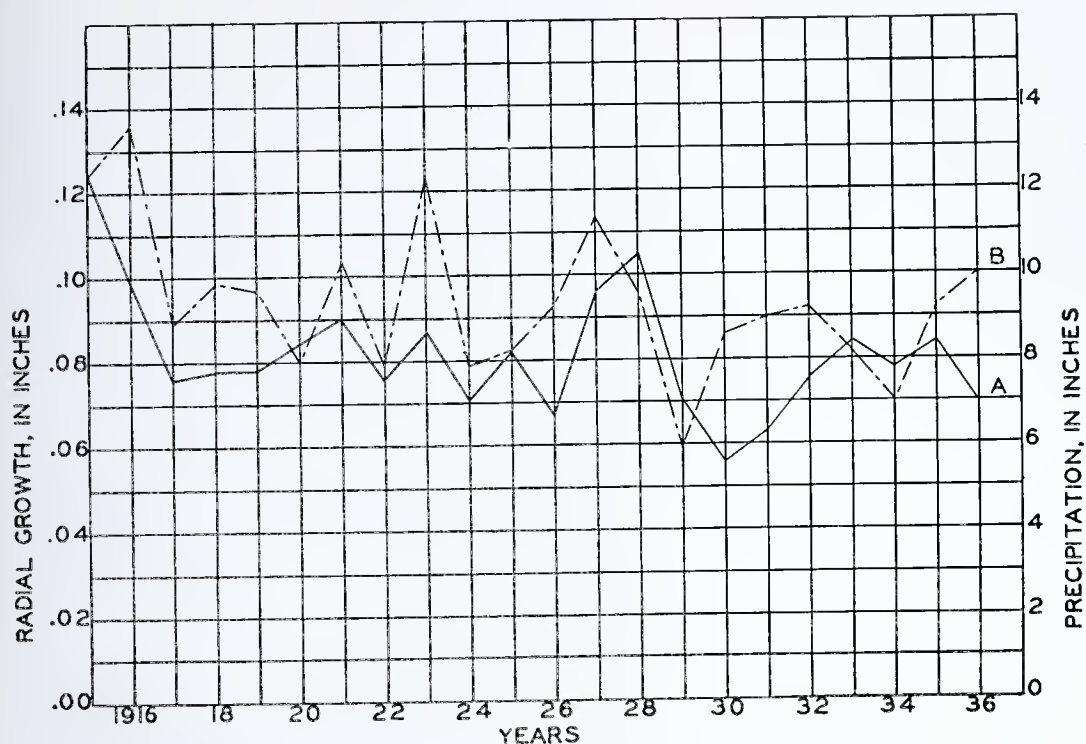


FIG. 1 Relation between growth of Douglas fir and precipitation.
 A. Growth of Douglas fir controls of 1936.
 B. Average precipitation from Jan.-Aug. for Laurier, Colville and Kettle Falls.

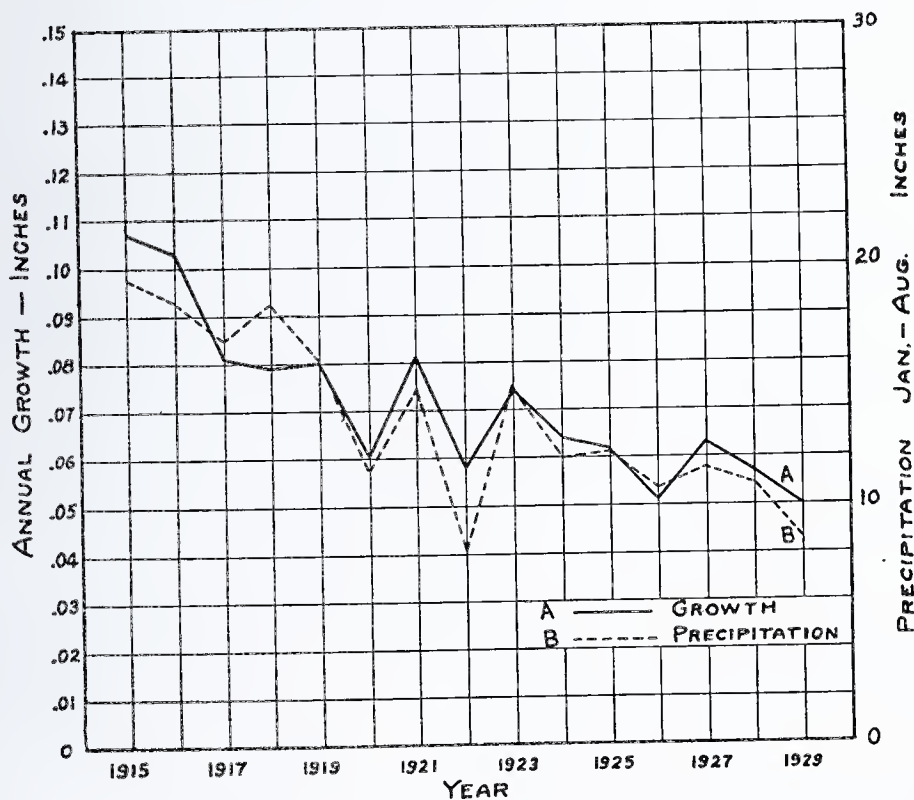


FIG. 2. Relation between growth of yellow pine and precipitation.
 A. Growth of yellow pine controls of 1929.
 B. Precipitation from Jan.-Aug. at Waneta, B.C.

controls in the Columbia valley and precipitation at Waneta, B.C., just across the International Boundary. This correlation, perhaps partly fortuitous, was obtained in the 1929 investigation, and the chart consequently does not show figures for later years.

It is a matter of common observation, however, that precipitation often varies considerably even at points relatively close together, and this is fully borne out by official records. Fig. 3 shows the precipitation from January to August at Laurier, Kettle Falls and Colville for the period 1916 to 1936, and at Northport from 1928 to 1936. It will be noted that the general form of all curves is the same, but there are two striking differences. In 1917 Colville (Curve D) had only 5.5 in. of precipitation in the eight months compared with an average of 10.5 in. for the other two points, and in 1932 Laurier had only 5.5 in. as compared with 11.6 in. for the other three. The year 1929 was the driest of all the years under consideration.

Suitability of Standards of Growth

When the effect of sulphur dioxide or other factors on tree growth is to be determined, precautions must be taken to insure that the trend of growth of the standards to be used for comparison is a normal one for the area under consideration. On the other hand, if a particular group of trees has been bored for use as a standard it may be neglected as such only when fully adequate reasons exist. Such a case, in fact, arose in the present investigation.

In 1929 five yellow pine groups, situated along the Columbia River from two to thirty-five miles south of Kettle Falls, well beyond the zone in which sulphur dioxide injury could have taken place, were chosen as standards of comparison with those growing up the river closer to the boundary. The growth of these control groups is shown in Fig. 4. It will be observed that the trends of growth for Groups 1, 3, 4 and 5 are all very similar throughout. The trend for No. 2, a group growing about two miles south of No. 1 and two miles east of No. 3, was similar to that of the others up to the end of 1923. In the four years 1920 to 1923, the average growth of the 100 trees of this group was 0.019 in. less than that of the 200 trees in the other four groups; then followed a short period of growth rapidly increasing in relation to that of the other groups, in spite of precipitation substantially less than in 1923; finally, in the four years 1926 to 1929 the average growth of No. 2 was 0.019 in. greater than that of the others, but with a similar trend in harmony with the precipitation for that period. This indicates strongly that Group 2 was for a period subject to some influence that did not affect the other four groups, and that its trend was quite abnormal, thus disqualifying it for use as a standard of growth. It was therefore discarded in the setting up of a standard for yellow pine in the study of 1929.

The cause of this abnormal behavior of a group of 100 trees is not definitely known, and the only clue is found in the field note made at the time the trees

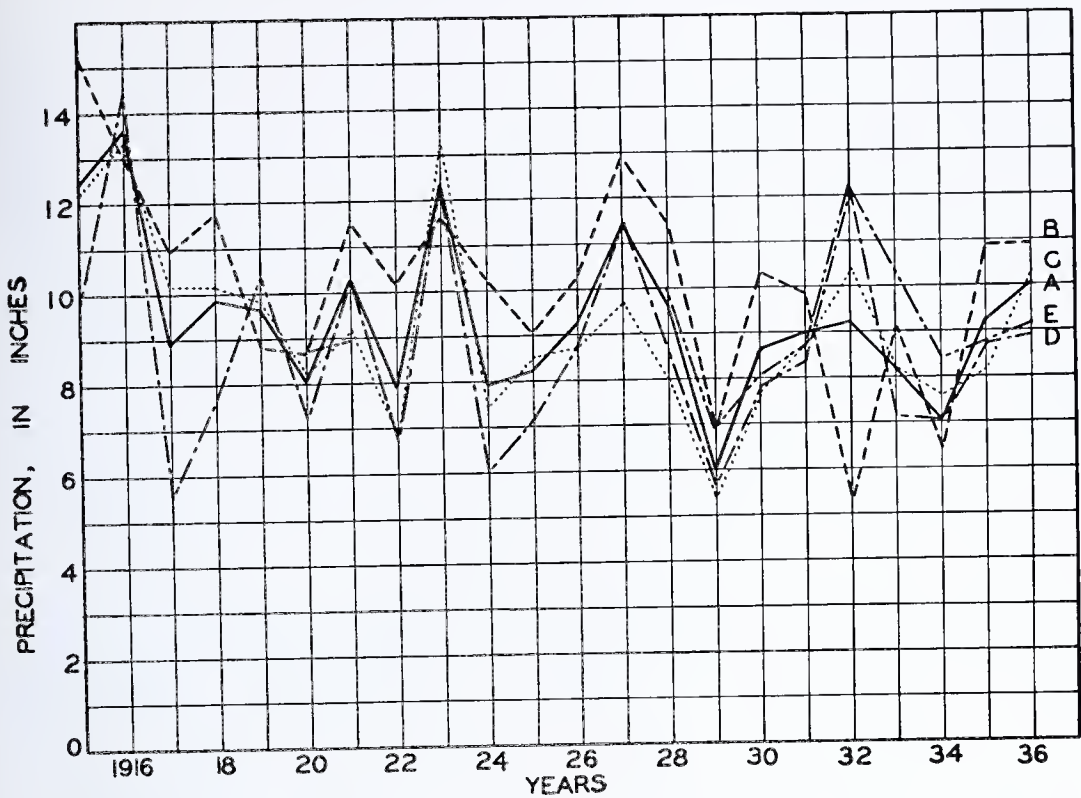


FIG. 3. Varying precipitation from Jan.-Aug. at four points within radius of 17 miles.
 A. Average precipitation, Laurier, Colville and Kettle Falls.
 B. Precipitation at Laurier.
 C. Precipitation at Kettle Falls.
 D. Precipitation at Colville.
 E. Precipitation at Northport.

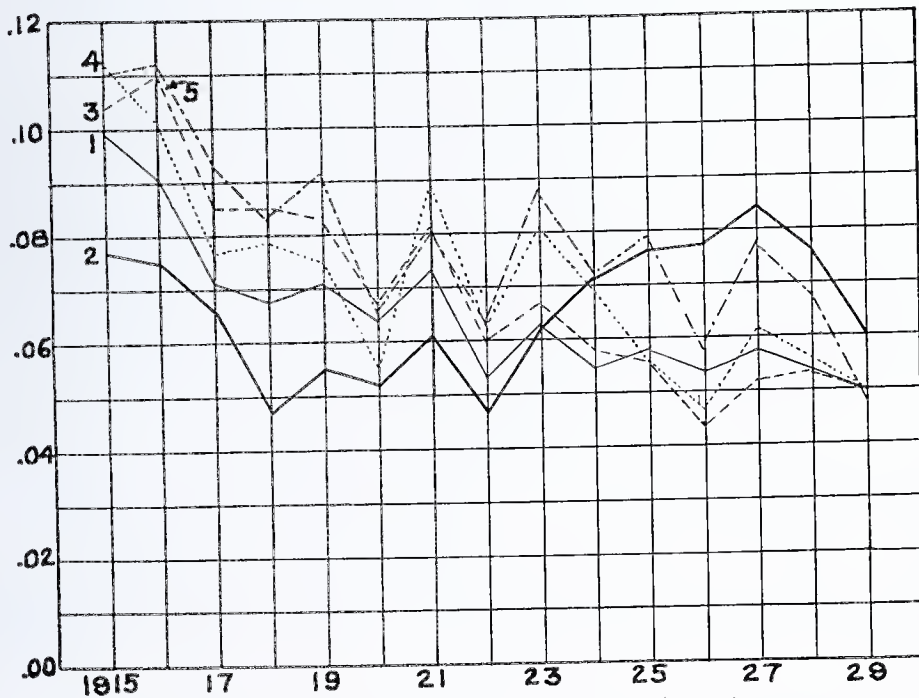


FIG. 4. Varying growth of yellow pine control groups of 1929.
 1. Growth of Group No. 1.
 2. Abnormal growth of Group No. 2.
 3. Growth of Group No. 3.
 4. Growth of Group No. 4.
 5. Growth of Group No. 5.

were bored, to the effect that the area had been logged over. This in itself does not distinguish this group from most others in Stevens County. It may be observed, however, that the rate of growth of the trees changed rather suddenly from a rate below the average for the locality to one above the average, and this suggests that some unfavorable factor affecting them up to the end of 1923 was then removed,—so completely removed, in fact, that conditions for growth became unusually favorable. This may be accounted for on the supposition that the trees were at first growing in a dense stand, with strong competition for the limited amount of moisture present, that the larger timber was removed in logging operations, and that the remaining trees had then a supply of moisture more nearly adequate to their requirements, accompanied by more favorable light conditions. Whether this hypothesis be correct or not, the fact remains that even a group of 100 trees may be entirely unsuitable as a standard of either absolute growth or growth trend.

Mention has been made of the fact that the trend of Group 2 did not closely follow that of precipitation during the short period of abnormally stimulated growth. It will be observed that the growth curve was at that time smooth in form, a characteristic which, it has been found in this investigation, is typical of trees growing in this area under some abnormal influence, such as sulphur dioxide. In this case the question of sulphur dioxide injury does not arise,

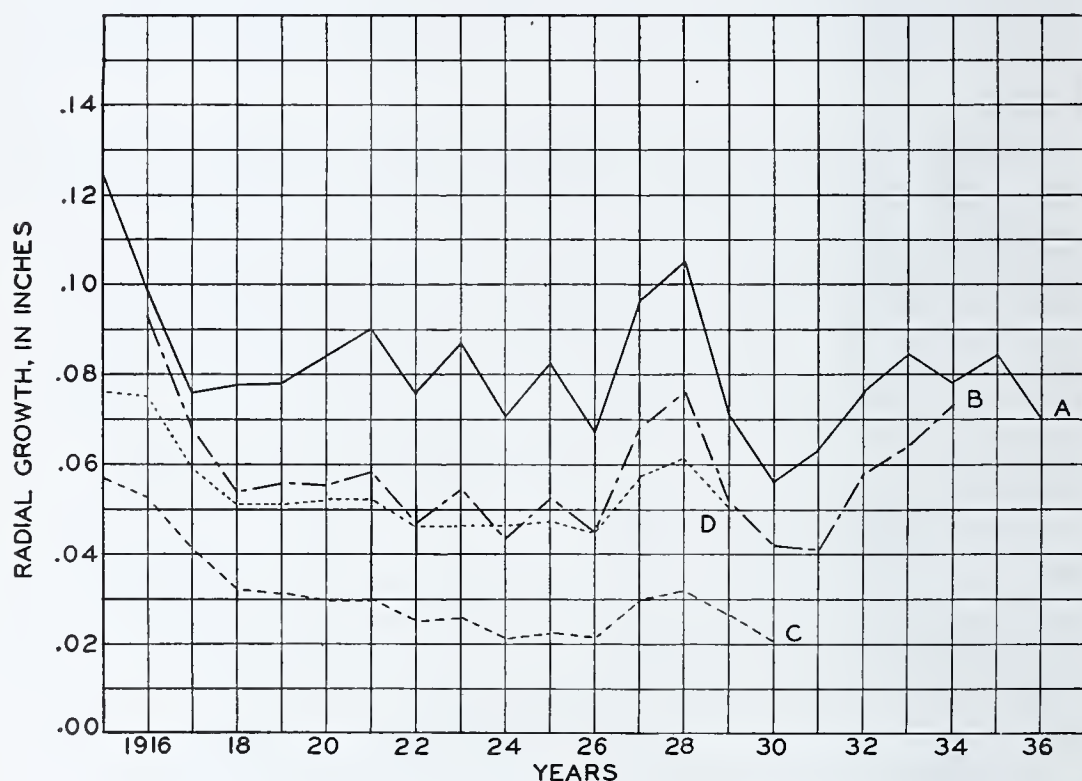


FIG. 5. Varying growth of Douglas fir controls in different years.

A. Controls of 1936.

C. Controls of 1930.

B. Controls of 1934.

D. Controls of 1929.

since the trees were well outside the zone of damage and their growth was stimulated rather than retarded.

It cannot be too strongly emphasized that the actual rate of growth of trees is of little or no value in determining whether retardation has occurred from any abnormal influence, such as sulphur dioxide. The trend of that growth is, however, of the utmost significance, whether actual growth be higher or lower than that of the controls. So also, any standard of growth may be suitable for comparison if its trend is normal, regardless of its absolute rate of growth. To illustrate this point there has been plotted in Fig. 5 the actual growth of the four Douglas fir controls of 1929, 1930, 1934 and 1936; the trees bored in 1930 grew very slowly compared with all the others, and those of 1936 showed the most rapid growth. Since it is not obvious from this chart whether or not the trends of growth in 1930 and 1936 were similar, the curves for these years have been redrawn in Fig. 6, the former on a scale three times that of the latter. It is at once evident that the trends of growth of these two groups are remarkably similar; in fact, in the period 1918 to 1930 the difference between the two curves is never more than 0.006 in., and the average difference for the 13 years is less than 0.003 in. on the scale of the 1930 standard. It may also be noted that—as

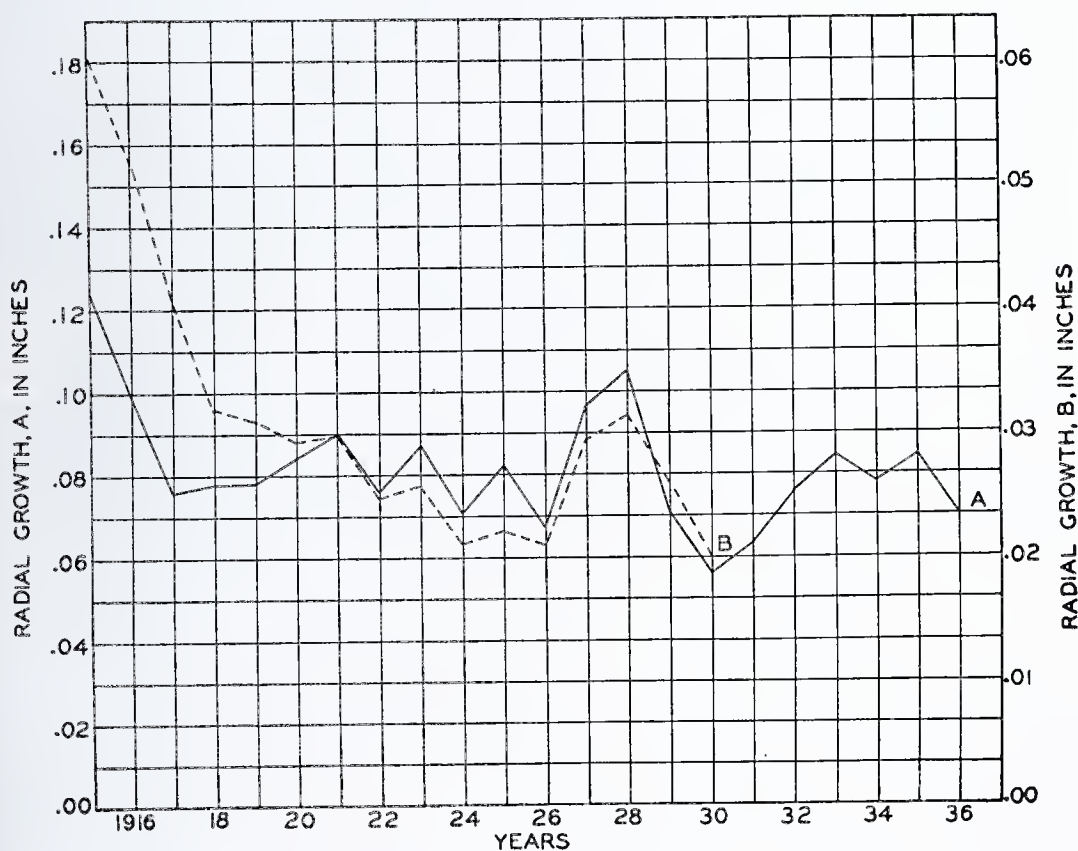


FIG. 6 Different absolute growth but similar growth trends in Douglas fir controls.
 A. Growth of controls of 1936.
 B. Growth of controls of 1930, on scale of three to one.

was not previously apparent—the relative responses of the two groups to variations in precipitation were almost identical. This indicates that while both are unsatisfactory as standards of absolute growth, the two are equally reliable as relative standards, that is, as standards of growth trends.

It will be obvious, from what has already been said regarding the degree of correlation between precipitation and tree growth, the differences found between controls, and certain unaccountable irregularities in diameter increment, that caution must be exercised in ascribing to sulphur dioxide, or any other particular factor, the decreased rate of growth observed in any given case. Only when the trend of growth has been considered from every possible angle, and the whole picture has been found relatively consistent, can it be said with any degree of assurance that an observed effect is attributable to any particular cause.

The records of diameter increment herein reported were examined as to the possible application of statistical methods of interpretation. It was concluded that the recorded periods of normal growth prior to sulphur dioxide fumigation were too short, the date of initial sulphur dioxide effect too uncertain, and the number of influencing factors too great, to permit the general application of any mathematical method of treatment. Calculations were frequently made, however, of the absolute growth of the controls and test trees during (*a*) short periods prior to the advent of sulphur dioxide in quantity, and (*b*) periods in which a smoke effect was suspected, or definitely known as a result of field observations. This method was found particularly useful in determining whether, with increasing distances from the source of sulphur dioxide, there was a corresponding decrease in the observed retardation. In this way, each group of trees served to some extent as a control for others growing in the vicinity.

Effect of Sulphur Dioxide

Correlation of Sulphur Dioxide Output and Retardation of Tree Growth

Before examining the evidence for injury to trees from sulphur dioxide it is essential to consider the question of the rate of output of this gas during the period under investigation, since any unaccounted-for change in the rate of growth of any particular trees can be ascribed to the action of sulphur dioxide only if there is correlation between them.

In Fig. 7 there has been plotted from data supplied by the smelting company the rate of emission of sulphur (as sulphur dioxide) from the Trail smelter during the whole period under review. (The actual tonnages are given in Chapter II, page 15.) It may be observed that the rate of sulphur dioxide emission was fairly uniform from 1915 to 1924 and that the 1916 rate was not exceeded until 1925. The five years 1926 to 1930, inclusive, constitute the period of greatest sulphur dioxide emission, and the maximum for any single year was reached in 1930. In 1932 and 1933 the output was below that of 1916

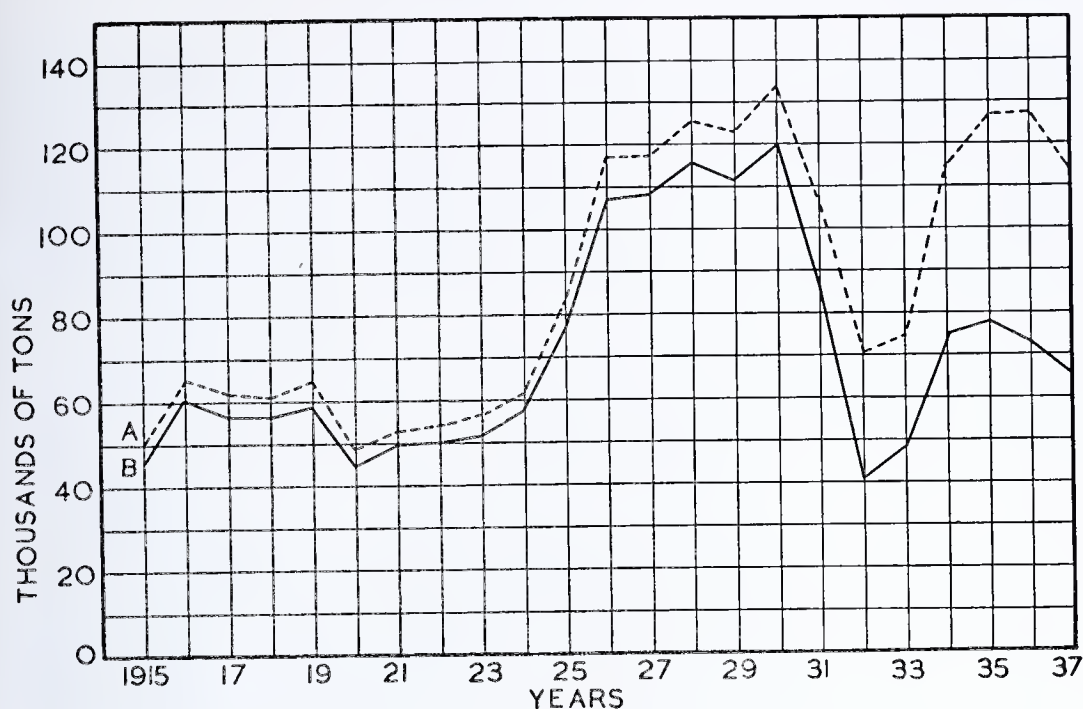


FIG. 7. Sulphur input and sulphur dioxide output of Trail smelter.

A. Sulphur charged to furnaces.

B. Sulphur emitted as sulphur dioxide.

Note:—The rate for 1937 is for first four months only.

and, while the rate was subsequently increased, the remedial measures and in particular the recovery of elemental sulphur prevented the attainment of a peak comparable with that of 1930. In the period subsequent to April 30, 1937, the latest date for which figures are shown in the chart, a further substantial decrease in sulphur dioxide output has been effected.

It should also be noted that a much smaller smelter than that at Trail was operated at Northport from 1916 to the spring of 1921 and that easements were purchased during this and an earlier period of operation on a total of nearly 8,000 acres of land. The maximum sulphur output during the period under review was about 14,000 tons per year, equivalent to 28,000 tons of sulphur dioxide.

Effect of Sulphur Dioxide on Yellow Pine

Studies of yellow pine were made in 1929, 1930 and 1934, but those of 1934 are now of the greatest interest since they relate to approximately the same area as those of the earlier years and, as will be seen from Fig. 7, also include a period of several years of reduced sulphur dioxide emission. Charts for 1929 and 1930 are therefore not shown, but the picture revealed by them is substantially the same as that found in the studies of 1934. The location of all groups of trees bored in 1930 and 1934, except those of the controls, is shown on the accompanying map.

The standard of yellow pine growth for 1934 was obtained by plotting the growth of 504 yellow pine trees in four groups from two to thirty-five miles south of Kettle Falls in the immediate Columbia River valley. The growth of the four groups was first plotted separately and these were combined in one chart only when they were found substantially alike. The curve of composite growth of these trees is shown in each of Figs. 8 to 13 in comparison with that of the trees whose reaction to sulphur dioxide it was desired to determine. Its correlation with precipitation for the full period was satisfactory.

Fig. 8 shows the growth of 201 yellow pine trees, constituting Groups 1, 6 and 7 (see map), near the Columbia River and as close to the Boundary as it was possible to find trees of suitable size. In this area the effect of sulphur dioxide from Trail was expected to be at a maximum, and an examination of the chart shows at once that the trees in question must have been subjected to some influence which did not affect the controls. Attention has already been called to the fact that a smooth curve, which in this region indicates the lack of any correlation with precipitation, suggests the action of some unusual influence, and it will be noted that the line representing the growth of these trees did not respond to precipitation until 1932. Even in the very dry season of 1929 growth was not appreciably less than in 1928, 1930 and 1931, indicating that the water available was approximately sufficient for the growth permitted by other factors. The greatest difference from the trend of the controls begins in 1927, the year

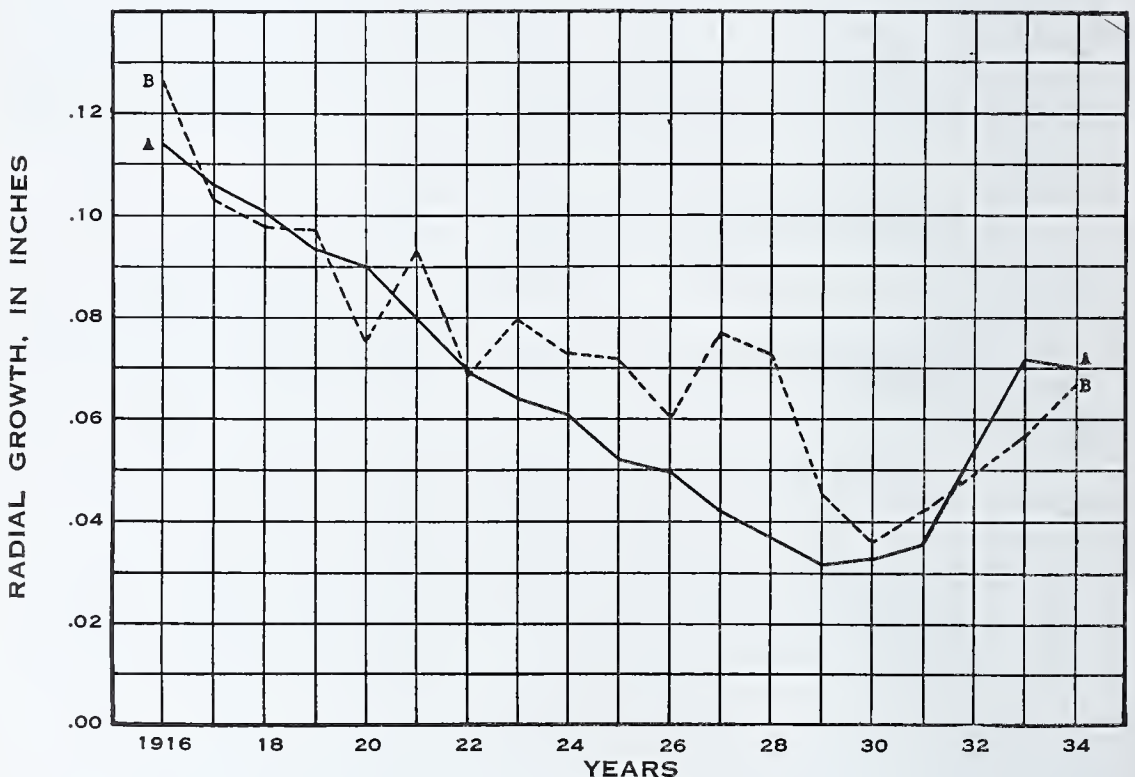


FIG. 8. Growth of yellow pine near International Boundary.

A. Groups 1, 6 and 7 of 1934.

B. Controls of 1934.

following the increase in output of sulphur dioxide at Trail, and continues for several years, though the effect in 1929 and 1930 was largely masked by the influence on the controls of the reduced precipitation in those years. In 1932 the trees in question showed a major increase in growth. This change coincided with a reduction in sulphur dioxide fumigation, and following that date the trees fully maintained their position in relation to the standard; in fact, their position in the years 1932 to 1934 was somewhat more favorable than in any other similar period since 1916. The correlation of growth retardation with that of sulphur dioxide emission at Trail may be considered close and the conclusion must be tentatively drawn that in this area sulphur dioxide has exerted a very adverse effect on the growth of yellow pine. If the effect noted is actually caused by sulphur dioxide from Trail, it may be expected to decrease farther down the river..

The trend of the curve from the beginning suggests that, while the effect of varying precipitation is not clearly shown, any adverse effect from sulphur dioxide or other unusual cause from 1916 to 1923 must have been relatively small. Such a cause might be fumigation with sulphur dioxide from either Trail or Northport, but light should be thrown on this point by a study of the succeeding curves. Since the Northport smelter had been permanently shut down in 1921, the small retardation indicated for 1923 to 1926 must be tentatively ascribed to sulphur dioxide from Trail.

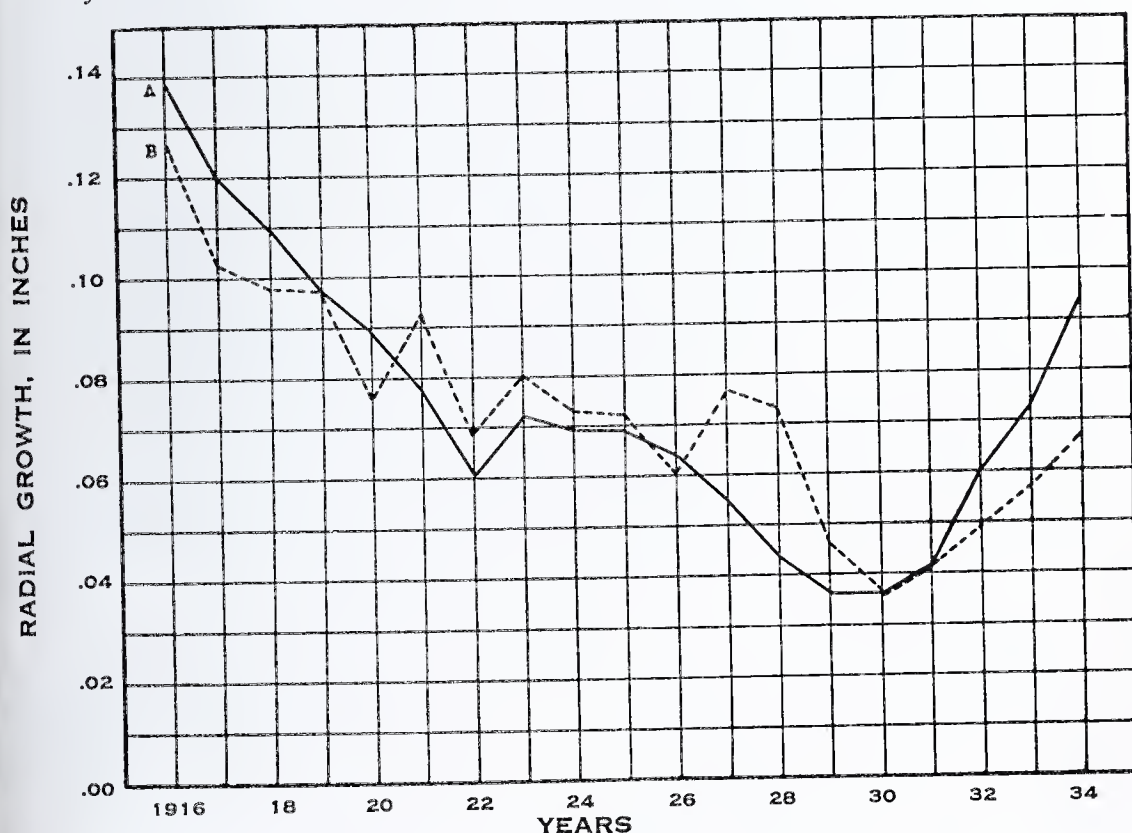


FIG. 9. Growth of yellow pine above Northport.
A. Groups 2, 3 and 5 of 1934.

B. Controls of 1934.

In Fig. 9 is shown the growth of 330 trees at points 2, 3 and 5 on the flat above and within three or four miles of the town of Northport. The trend of the growth curve of these trees from 1916 to 1921 is more definitely at variance with that of the controls than is that of Fig. 8, thereby showing a larger effect of the operation of the Northport smelter with increasing proximity. In 1923 there was a definite rise in the curve in response to the more favorable precipitation (an increase from 7.9 to 12.3 in. in the period of eight months), presumably on account of less influence from Trail fumigations as compared with the trees of Fig. 8. From 1925 to 1930 the curve assumes the smooth form typical of growth under the influence of sulphur dioxide, and in 1927 to 1929 it indicates a pronounced effect from the operation of the Trail smelter. In 1932 there was a sharp rise, corresponding to that of Fig. 8, and in subsequent years the trees of this locality more than maintained their position in comparison with the controls.

The growth of Groups 4, 8 and 9, comprising a total of 330 trees at Northport and some three to four miles down the river from that point, is shown in Fig. 10. The smooth form of the curve representing growth from 1916 to 1921 is maintained, but its trend is less strongly downward than that of previous groups, indicating a smaller effect from Northport. From 1923 to 1926 the trees were apparently beyond any appreciable influence of sulphur dioxide from

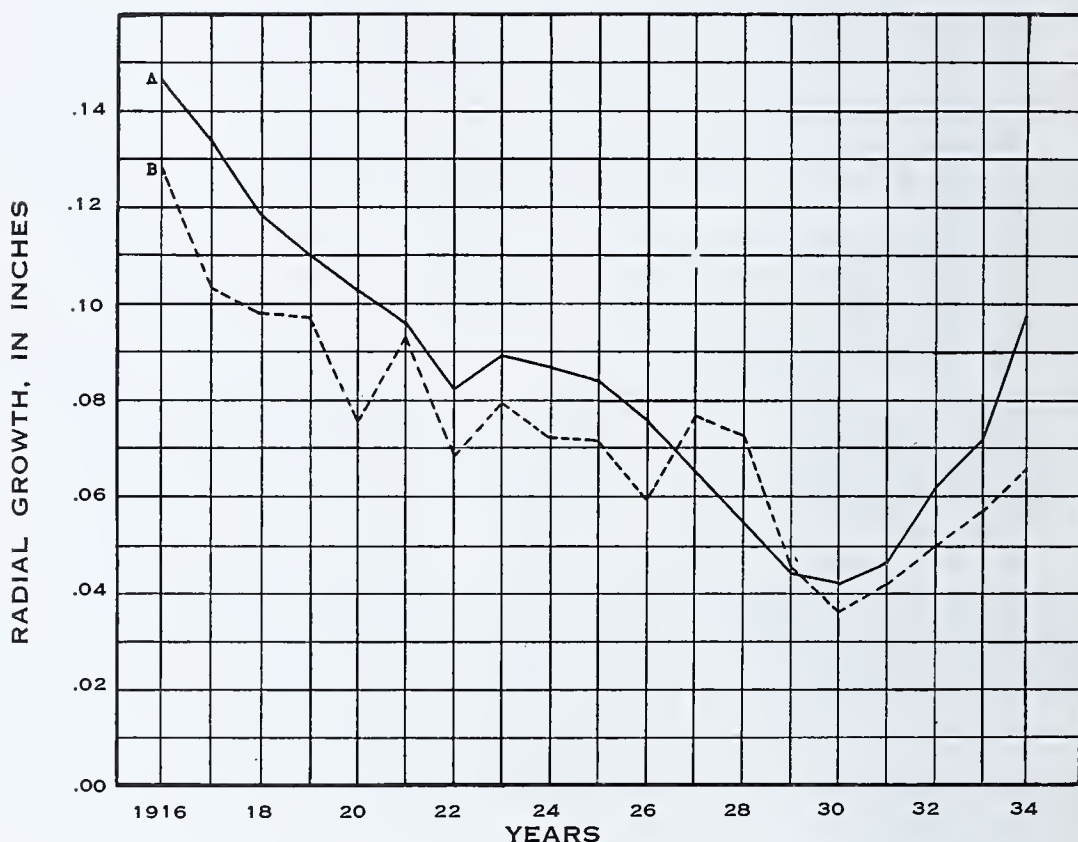


FIG. 10. Growth of yellow pine at and below Northport.

A. Groups 4, 8 and 9 of 1934.

B. Controls of 1934.

Trail, but their growth was substantially reduced from 1927 to 1929. It is to be particularly observed that the rate of growth changed from one greater than, to one substantially less than, that of the controls. The improvement from 1932 to 1934, relative to the controls, was again pronounced.

Fig. 11 is of particular interest in that it shows for 220 trees in Groups 10 and 19, growing within three miles of Marble, a definite precipitation effect throughout the whole period. It does not show any retardation in growth prior to 1927 as a result of the operation of either smelter. Even in 1927 and 1928 the amount of retardation is of the order of only about 0.015 to 0.025 in. per year.

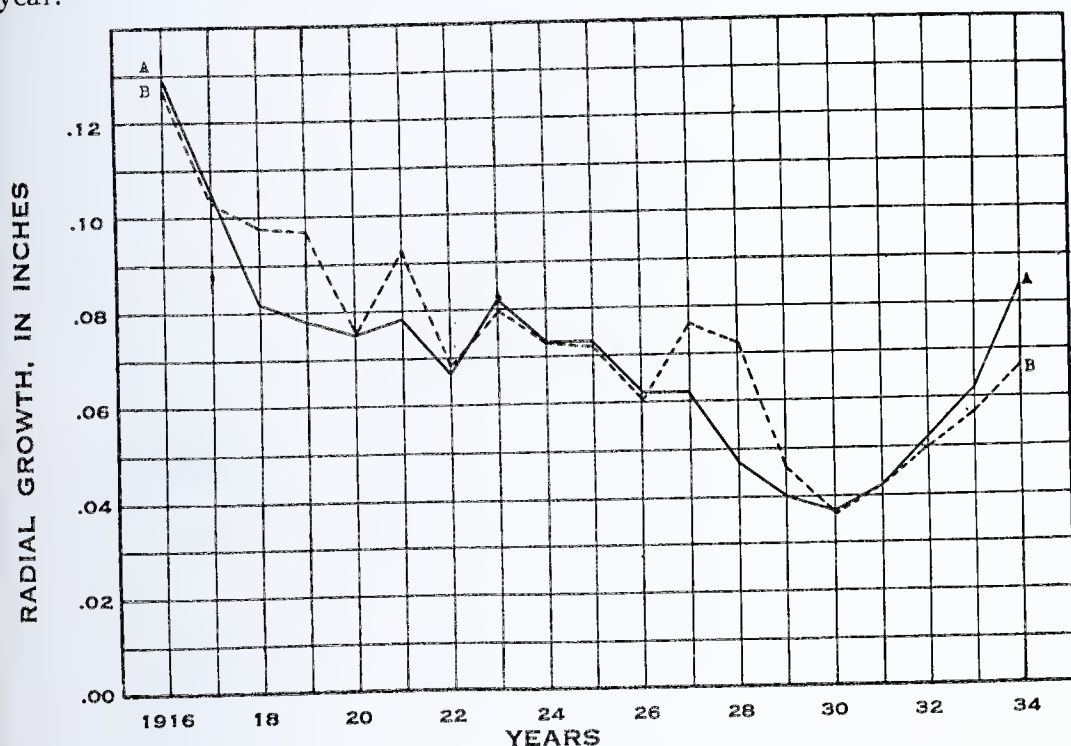


FIG. 11. Growth of yellow pine below Marble.
A. Groups 10 and 19 of 1934.

B. Controls of 1934.

In Fig. 12, representing the growth of Groups 11 and 12, 220 trees from one to four miles above Bossburg, the trends of the two groups are almost identical. Attention is called to the fact that in their previous history these trees had, on the average, grown more slowly than the controls. It must be concluded that even in 1927 and 1928 the retardation in growth due to sulphur dioxide, while still perceptible, was very small.

Fig. 13, showing the growth of 220 trees in Groups 13 and 14, within three miles of the town of Marcus, may be taken as a record of groups not retarded by the action of any unusual influence. There is good correlation with precipitation throughout, including the years 1927 and 1928, although in these two years it is less than the response of the controls, partly as a result of its smaller decrease in growth in 1926.

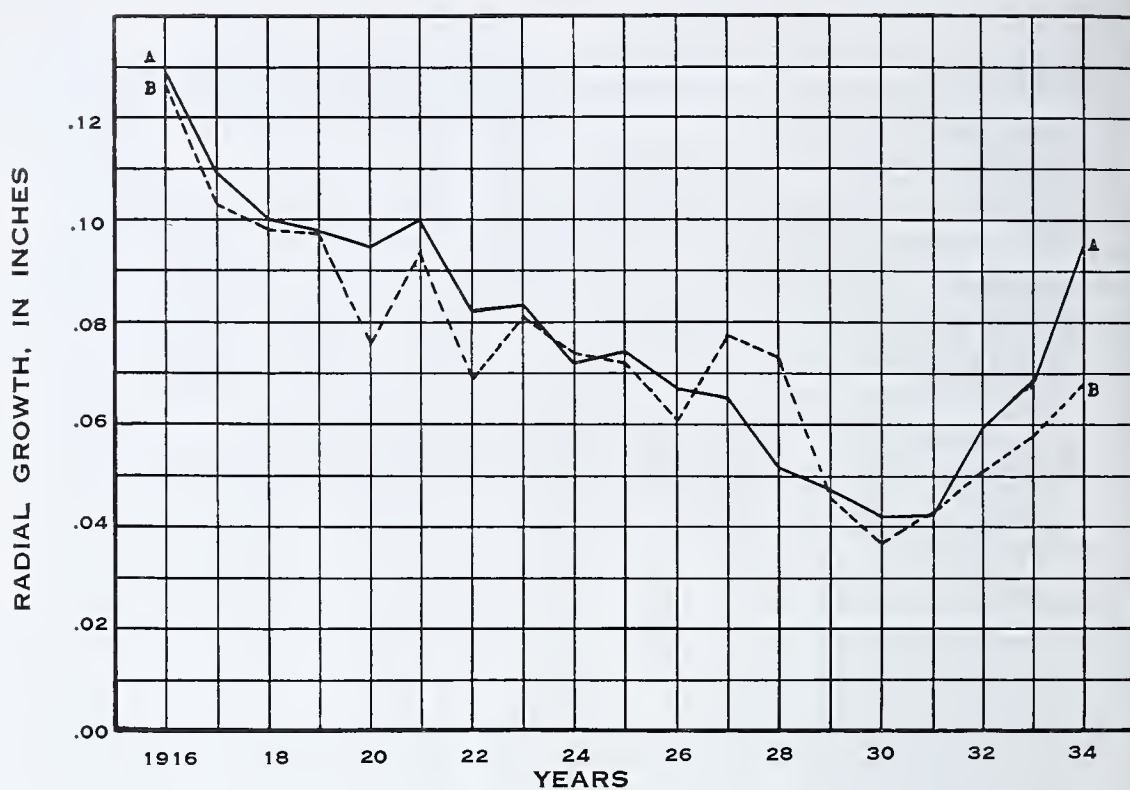


FIG. 12. Growth of yellow pine above Bossburg.

A. Groups 11 and 12 of 1934.

B. Controls of 1934.

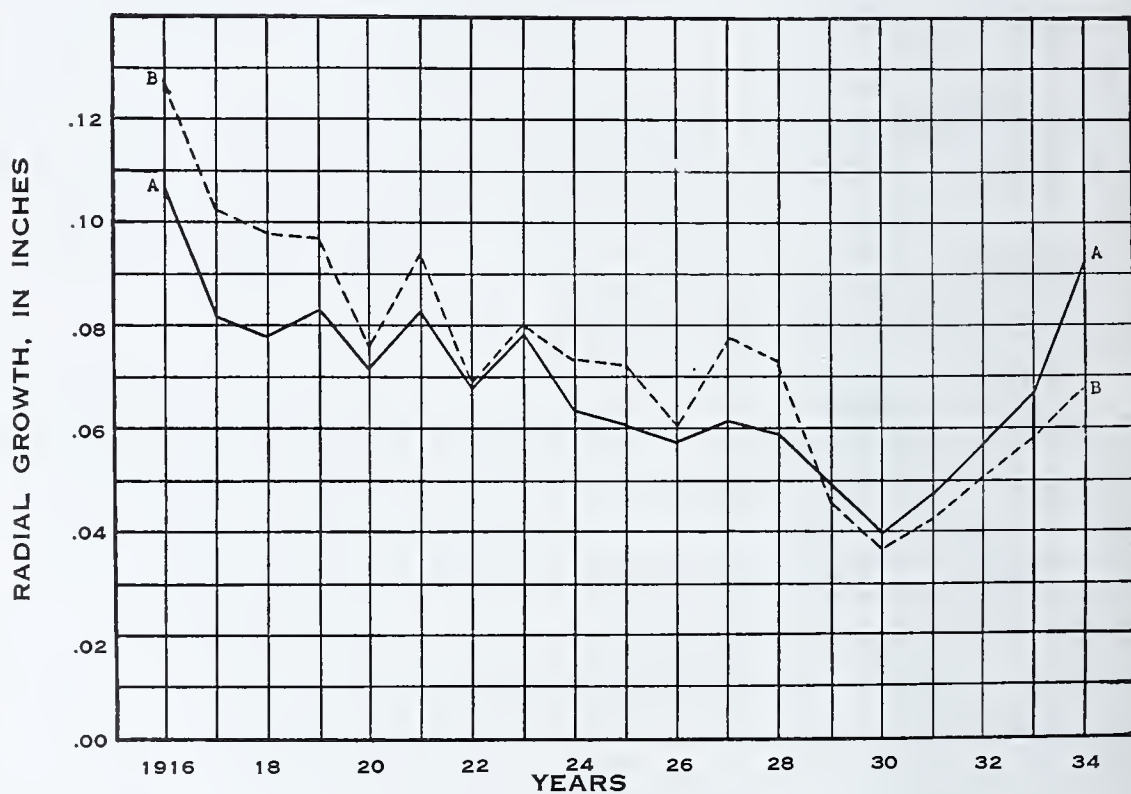


FIG. 13. Growth of yellow pine near Marcus.

A. Groups 13 and 14 of 1934.

B. Controls of 1934.

The average diameter at breast height of the yellow pine controls was 10.30 in.; those of the groups represented by Figs. 8 to 13 were 10.11, 9.52, 10.45, 9.22, 10.06 and 10.46 in., respectively.

Considering the behavior of all of these groups of yellow pine trees, it appears that the picture is a consistent one and that the conclusions drawn from one group are largely confirmed by the behavior of adjoining groups. From field observations it is believed that many pines have been killed in the valley of the Columbia River immediately below the International Boundary by sulphur dioxide from Trail. Substantial injury has evidently been caused by sulphur dioxide from Trail down to a point a little below the town of Northport, and for part of this distance the effect is perceptible as far back as 1923. From Northport to Bossburg the effect tapers off to the vanishing point. The effect from the operation of the Northport smelter is less marked than from that of the Trail smelter, as might be expected from its smaller size. Damage extends from a point near the Boundary to about the town of Marble, and over much of this distance it is evident chiefly through the masking of the precipitation effect.

Particularly notable is the recovery of all groups when the emission of sulphur dioxide was reduced, although it must be remembered that the controls were greatly stimulated by the increased precipitation, and only the improvement of the tested trees in relation to the controls can be attributed to the change in the sulphur dioxide factor. With the possible exception of Groups 1, 6 and 7 (Fig. 8), all these groups show a better recovery than do the controls. Averaging for 1916 the actual growth of the 1521 yellow pines, it is found to exceed that of the 504 controls by 0.004 in., while in 1932, 1933 and 1934 the average excess above the growth of the controls was 0.007, 0.015 and 0.022 in., respectively. This suggests the possibility that the light fumigations of the last-named years may have been slightly beneficial. Another possible explanation is that in 1933 and 1934 the control trees did not receive quite as favorable precipitation as did those farther up the valley, but there is no evidence to this effect.

It may also be observed here that the conclusions reached in this study of yellow pine are in harmony with field observations on trees, shrubs and field crops in this area, with the sulphur content of the needles of conifers, and with the percentage of sulphur dioxide in the atmosphere.

Effect of Sulphur Dioxide on Douglas Fir

Douglas fir were studied in 1929, 1930, 1934 and 1936, and the reasons for these repeated investigations have already been given. Since, however, there was considerable duplication in the area covered and the groups bored, details will be given only of those groups of the earlier studies that were not later duplicated. None of the 1929 results need be given, but most of those of 1930, one group of 1934 and all those of 1936 are of interest.

The growth of the Douglas fir controls has already been given in Fig. 5. Those of 1930, consisting of Groups 18 to 20, contained a total of 660 trees growing from six to fifteen miles southeast of the Columbia River at points far removed from the smoke area. As already pointed out (see Fig. 5), the growth of these trees was extremely slow. Since by the time the interpretation of the 1930 cores was required those of 1934 were also available, it was decided to combine the standards of 1929, 1930 and 1934 in a single standard for the interpretation of growth up to 1930. This gave a total of 1695 trees, and the curve showing the growth of these trees appears in Figs. 14 to 18.

Fig. 14 records the growth of Groups 3 and 13 of 1930, a total of 220 trees from one to two miles south of the International Boundary and well to the east of the Columbia River valley. While in this case the trends of growth of these trees and the controls are different, it will be noted that the trees responded to precipitation throughout the period. There is no evidence of retardation in growth as a result of the operation of the Northport smelter, and it is believed that the effect of gas from Trail was small, at least to 1927, when the response to favorable precipitation was less than that of the controls.

The growth of 219 trees in Groups 1 and 2 of 1930, at an elevation of about 3,000 feet on the mountains northeast of Northport, is shown in Fig. 15. The general trend of growth of these trees is very similar to that of the previous groups, but the smooth form of the curve since 1927 suggests that there was

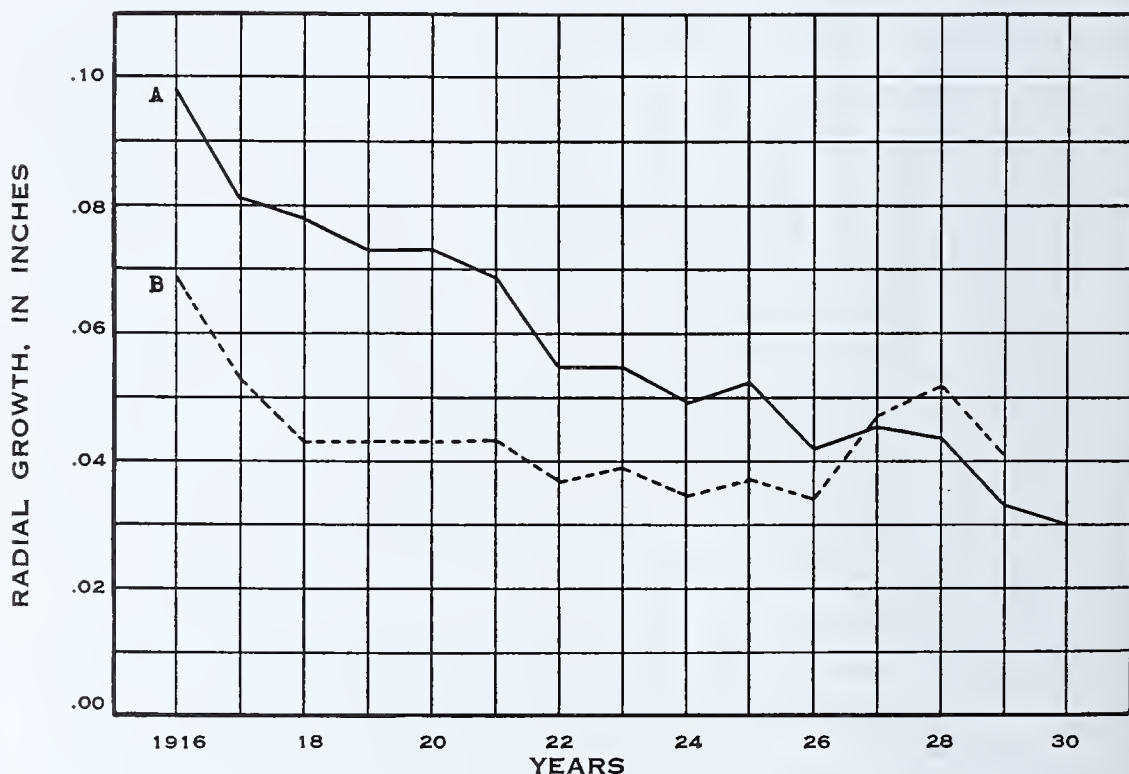


FIG. 14. Growth of Douglas fir east of Columbia River valley, near International Boundary.
A. Groups 3 and 13 of 1930. B. Controls of 1929, 1930 and 1934.

enough sulphur dioxide present to mask the effect of precipitation. This apparent retardation may, however, have been due to the action of tussock moths, since the field notes stated that these were prevalent in both groups. It is probable that the groups represented by Figs. 14 and 15 were on the very edge of the area of retardation.

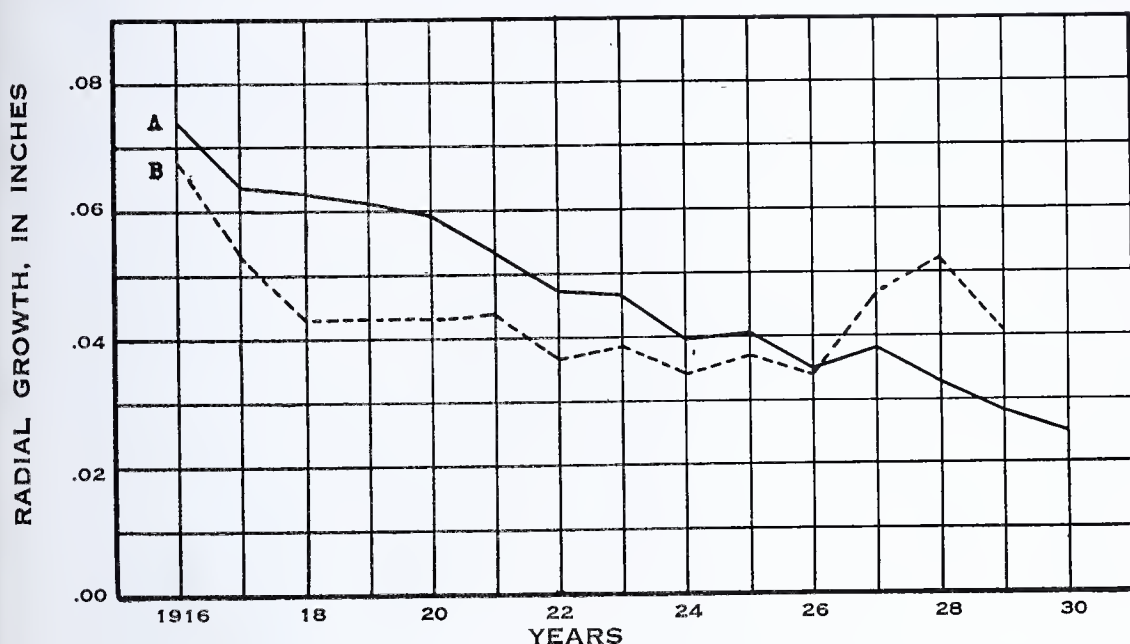


FIG. 15. Growth of Douglas fir on mountains near Columbia River.
A. Groups 1 and 2 of 1930. B. Controls of 1929, 1930 and 1934.

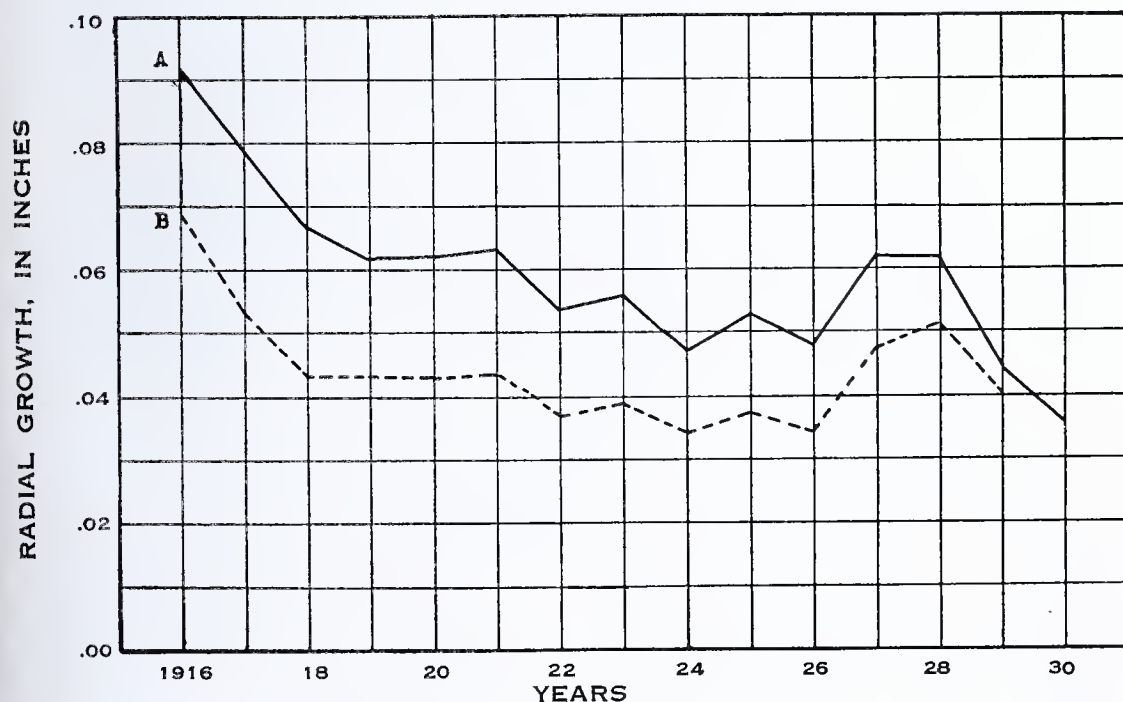


FIG. 16. Growth of Douglas fir near Deep Creek.
A. Group 16 of 1930. B. Controls of 1929, 1930 and 1934.

The curve in Fig. 16, representing the growth of 106 trees in Group 16, about one mile from Deep Creek and a little to the southeast of Northport, shows a good response to precipitation throughout the period and reveals no effect from the operation of either the Northport or Trail smelter, although some gas from Trail has been detected in this locality.

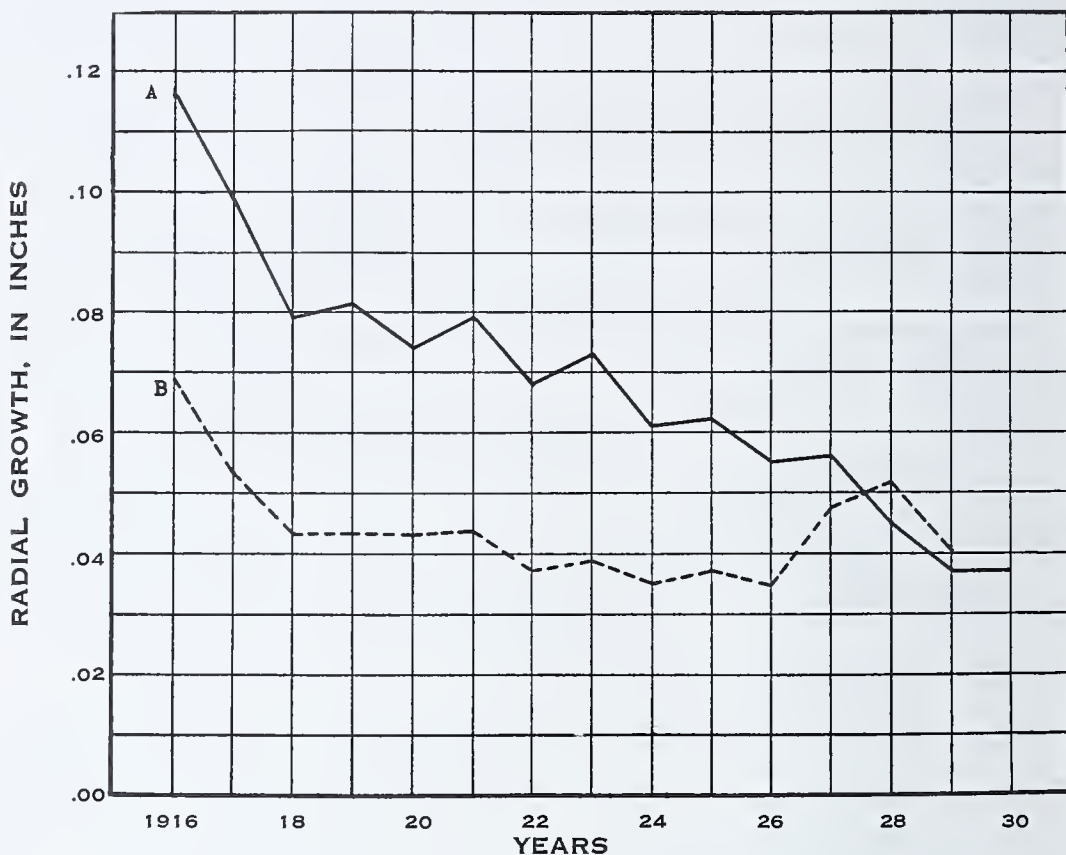


FIG. 17. Growth of Douglas fir below Marble.

A. Group 4 of 1930.

B. Controls of 1929, 1930 and 1934.

The growth of 110 trees in Group 4, near the Columbia River and about two miles below Marble, is shown in Fig. 17. This shows no effect from sulphur dioxide until 1927, when the response to favorable precipitation was slight, and following which the curve assumed the smooth form typical of trees affected by sulphur dioxide.

An interesting case is that of Fig. 18, which shows the growth of 220 trees in Groups 9 and 12 of 1930, across from Marble and about one and one-half miles back from the river. The growth of the two groups has been plotted separately in order to show the erratic behavior occasionally encountered. Group 9 is fairly consistent in its trend and it may be said to show little or no effect from sulphur dioxide at any time. The curve representing Group 12 crosses that of Group 9 at several points. In 1918 it showed a pronounced rise, while the curve of the adjoining Group 9 was making an equally pronounced fall in keeping with the standard curve. In 1923 the curve showed a substantial drop, again in the

direction opposite to that of the other curves. It did not rise in 1927, but in view of its previous irregularity it is doubtful whether this is the effect of sulphur dioxide. It is possible that both groups were slightly retarded in the period beginning with the year 1927.

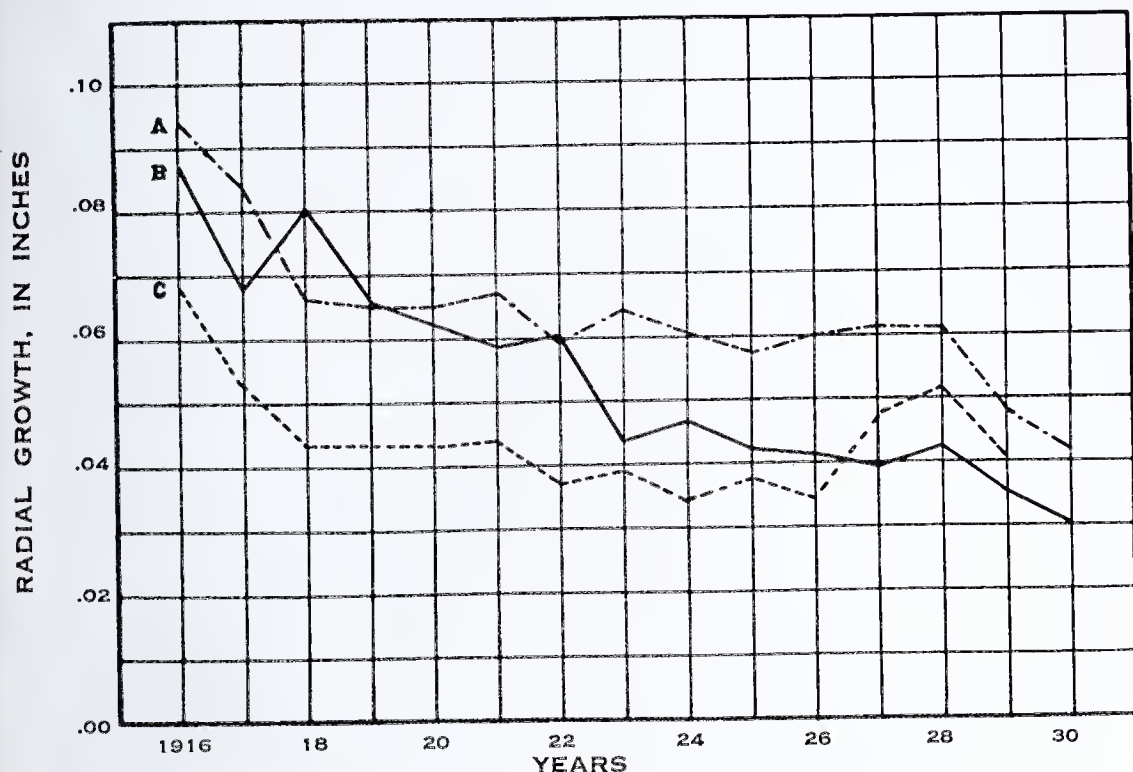


FIG. 18. Growth of Douglas fir west of Columbia valley, near Marble.

A. Group 9 of 1930.

B. Group 12 of 1930.

C. Controls of 1929, 1930 and 1934.

The only 1934 group which need be noted is No. 6, consisting of 60 young and rapidly growing trees of an average diameter of 7.43 in. at Velvet on Little Sheep Creek, not far from the Boundary, as shown in Fig. 19. To facilitate the interpretation of this curve the average precipitation at Colville and Kettle Falls was plotted, as well as the growth of the two standards. The effect of precipitation is very striking and it must be concluded that sulphur dioxide at no time adversely affected the growth of these trees.

The Douglas fir groups of 1936 are of greater interest, because the period includes that in which remedial measures went into effect at the Trail smelter and yellow pine showed complete recovery at all points in the valley of the Columbia River.

Fig. 20 shows the growth of 110 trees in Group 3 of 1936, situated on Deep Creek about four miles southeast of Northport. While the growth trend of these trees is not identical with that of the controls, there is no evidence of re-

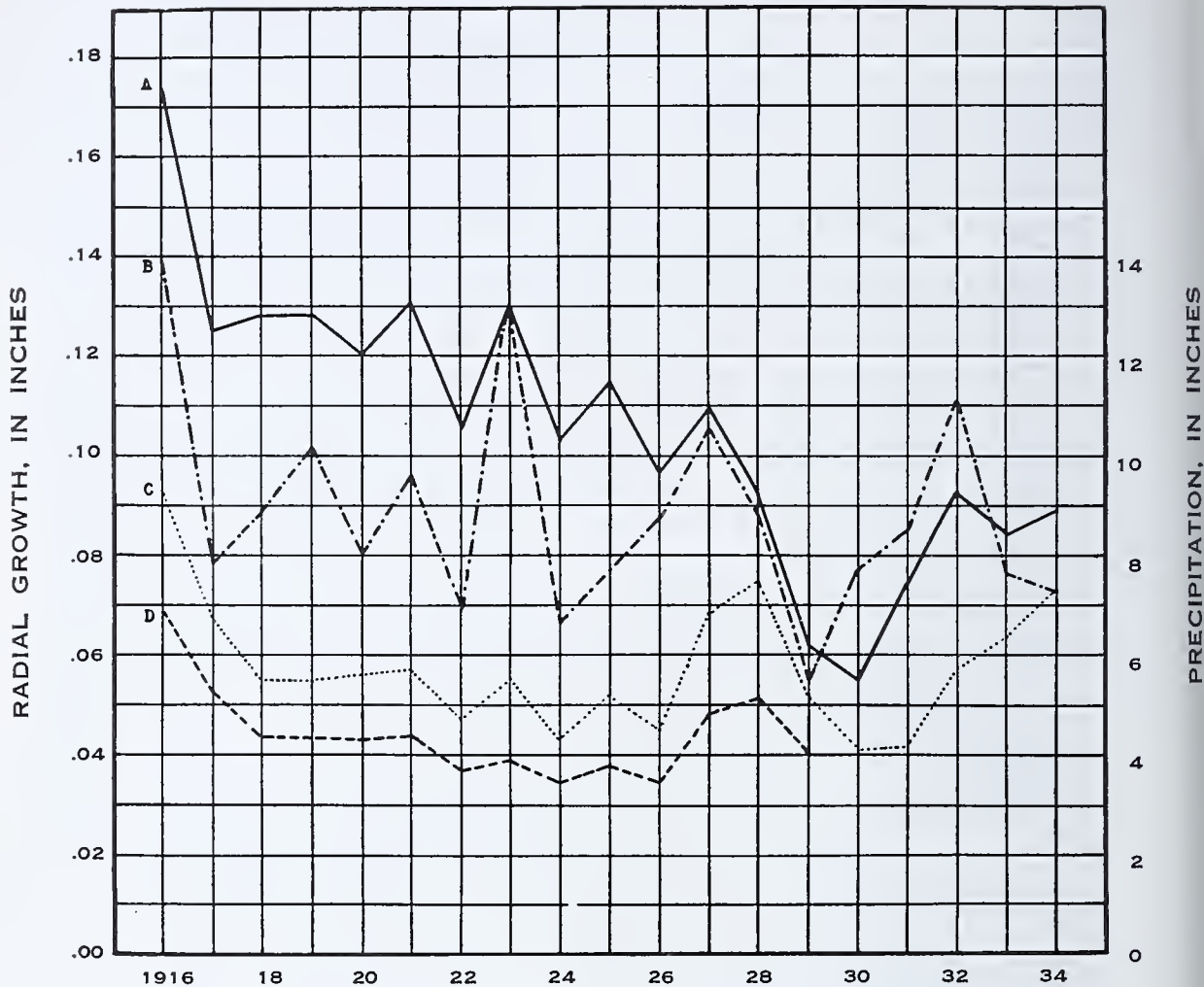


FIG. 19. Growth of Douglas fir at Velvet.

A. Group 6 of 1934.

B. Average precipitation, Colville and Kettle Falls.

C. Controls of 1934.

D. Controls of 1929, 1930 and 1934.

tardation due to the operation of either the Northport or Trail smelter. The large increase in growth since 1931 may be ascribed entirely to the more favorable precipitation during that period.

The 110 trees of Group 4 were also situated on Deep Creek, but about one and one-half miles nearer to its mouth and therefore more exposed to fumes from both Northport and Trail. As shown in Fig. 21, there is evidence here of retardation during the period of operation of the Northport smelter. The abrupt slackening of growth in 1922 cannot be fully accounted for by the decreased precipitation of that year, but there is no evidence of further injury from sulphur dioxide until 1927 or 1928, when for several years moderate retardation occurred, followed by gradual recovery, which was complete by 1934.

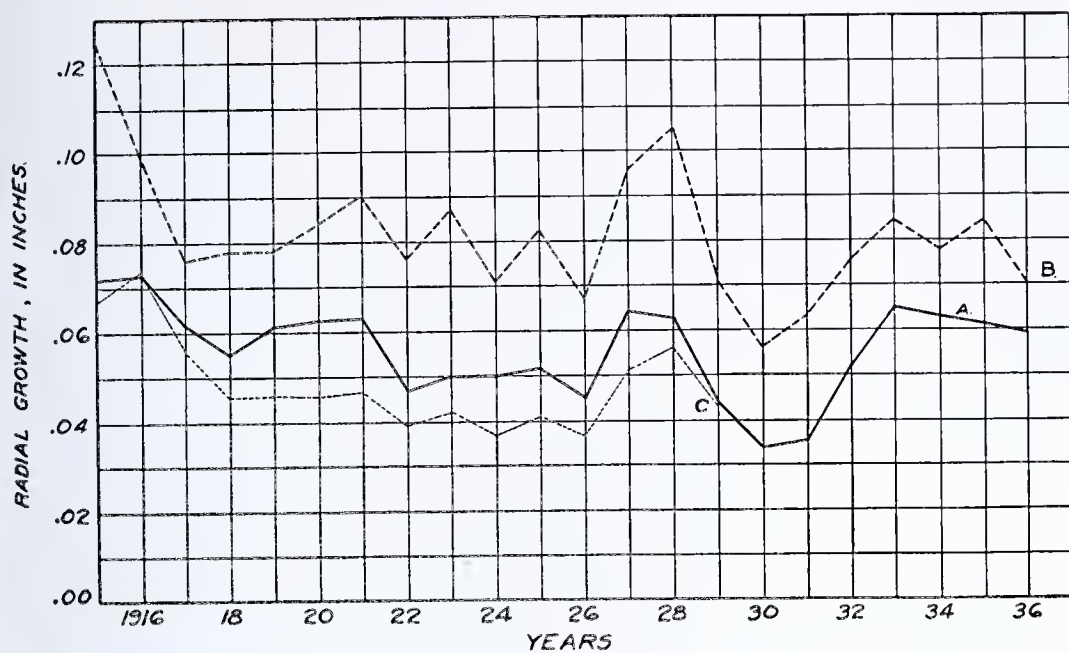


FIG. 20. Growth of Douglas fir four miles up Deep Creek.
 A. Group 3 of 1936. (Group 1 of 1934).
 B. Controls of 1936.
 C. Controls of 1929, 1930 and 1934.

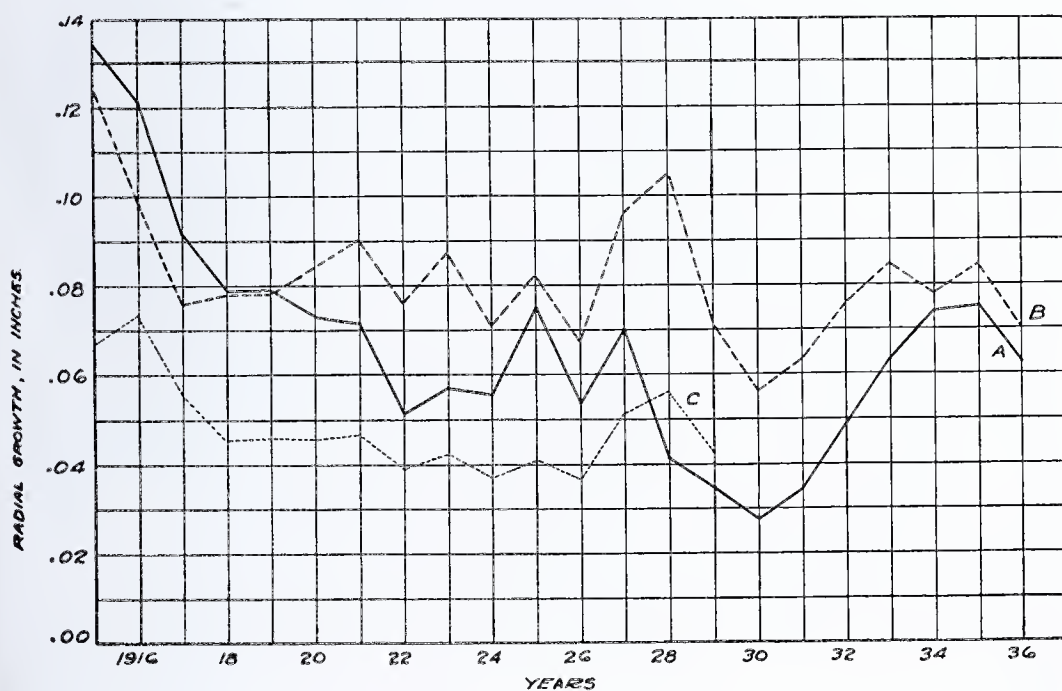


FIG. 21. Growth of Douglas fir two miles up Deep Creek.
 A. Group 4 of 1936 (Group 2 of 1934).
 B. Controls of 1936.
 C. Controls of 1929, 1930 and 1934.

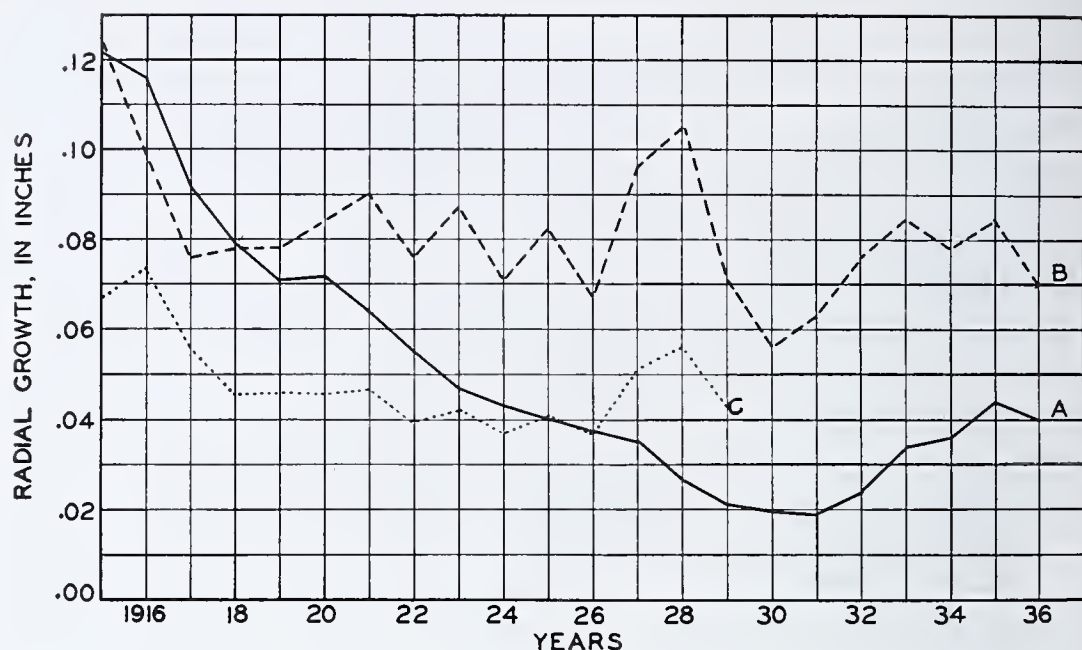


FIG. 22. Growth of Douglas fir along Columbia River northeast of Northport.
 A. Group 5 of 1936 (Group 4 of 1934).
 B. Controls of 1936.
 C. Controls of 1929, 1930 and 1934.

A very different picture is presented in Fig. 22, representing the growth of 59 trees in Group 5 of 1936, on the east bank of the Columbia and only about seven miles from the Boundary, the point nearest to the source of sulphur dioxide at which a sufficient number of trees could be found for study. Some retardation apparently occurred as a result of the operation of the Northport smelter, but the effect of the Trail operations was seen by 1923 or earlier. By 1927 the trees in this group were growing less than half as rapidly as the controls of 1936, with which they had previously kept pace. Recovery began in 1932 and in four years the rate of growth of the trees was more than doubled, but recovery was still far from complete.

Another group in the main Columbia valley, but a little lower down the river, is No. 8 of 1936, consisting of 40 trees on the bench slightly above and opposite Northport, as shown in Fig. 23. This reveals a reduction in growth during the period of operation of the Northport smelter and a levelling off when that plant was closed, but without, it may be noted, any effect from precipitation, indicating that even by 1923 there was a slight effect from sulphur dioxide from Trail. As in the case of Group 5, serious injury is shown from 1927 to 1931, with recovery beginning in 1932. In 1935 and 1936 recovery may be said to be complete.

In this case an estimate has been made of the total (cumulative) decrease in growth caused by the action of sulphur dioxide from Trail, an estimate which is facilitated by the fact that the period 1922 to 1936 began and ended with

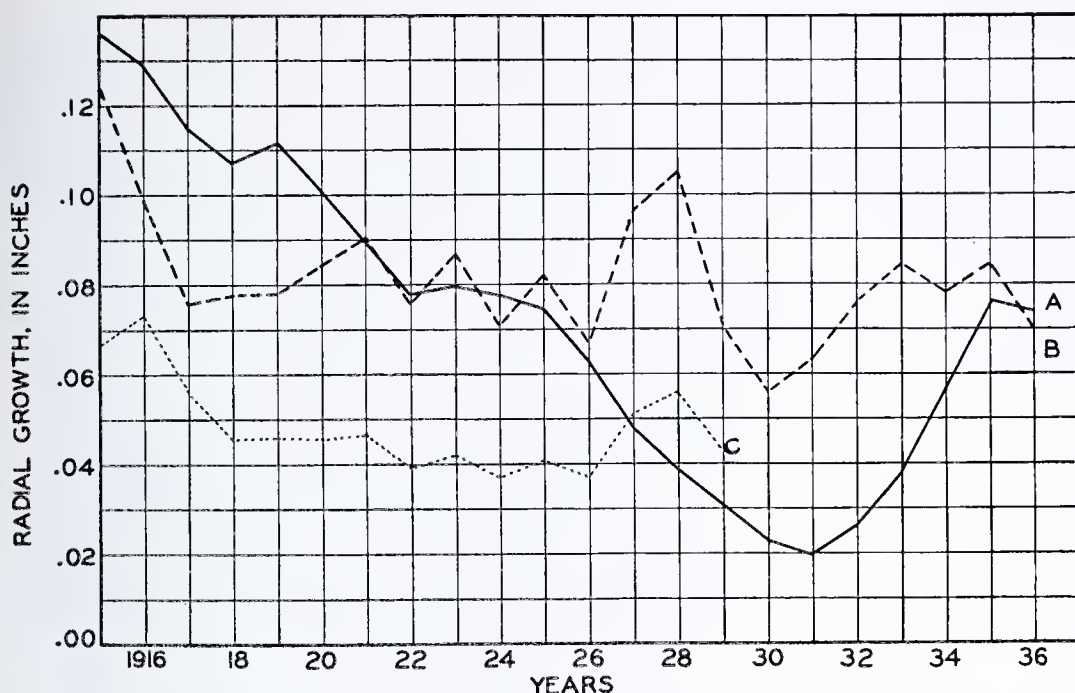


FIG. 23. Growth of Douglas fir on flat above Northport.

A. Group 8 of 1936 (Group 5 of 1934).

B. Controls of 1936.

C. Controls of 1929, 1930 and 1934.

substantially the same growth by the trees of Group 8 and the controls of 1936. Adding together the differences (radial) between the two curves for this period, and doubling the result to obtain diameter, one finds 0.75 in. as the probable loss in diameter increment which has resulted from the action of sulphur dioxide from the Trail smelter.

Groups 6 and 7 of 1936, consisting of 170 trees growing well back from the Columbia in the valleys of tributary creeks, have received more study than any others, but the record of growth has been found difficult to interpret. These groups correspond to Groups 17 and 14, respectively, of 1930, and Groups 10 and 3 of 1934. In this case the same groups of trees were chosen, and, indeed, many of the same trees were bored, in order to obtain a check on the earlier work and to determine the growth of the trees in the later period.

The growth of these trees is shown in Fig. 24. It is obvious that very pronounced retardation has occurred. Some of this took place during the operation of the Northport smelter and the return of the precipitation effect in 1922 suggests that the retardation should be ascribed to that cause, although it may be noted that there was no recovery in the rate of growth. A further and much greater deviation in growth trend, as compared with that of the controls, took place in subsequent years, beginning in 1927 and continuing to the end of the period under review, with only moderate recovery from 1932 to 1936. This deviation might well be ascribed to the action of sulphur dioxide from Trail

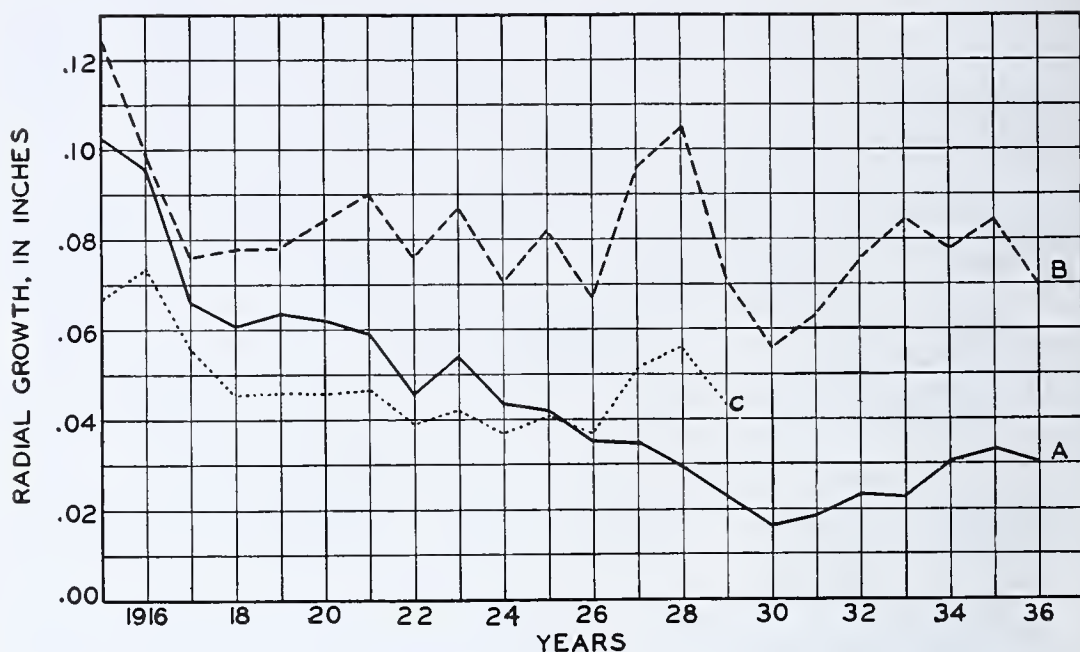


FIG. 24. Growth of Douglas fir on Sheep and Nigger Creeks.

A. Groups 6 and 7 of 1936 (Groups 17 and 14 of 1930 and Groups 10 and 3 of 1934).

B. Controls of 1936.

C. Controls of 1929, 1930 and 1934.

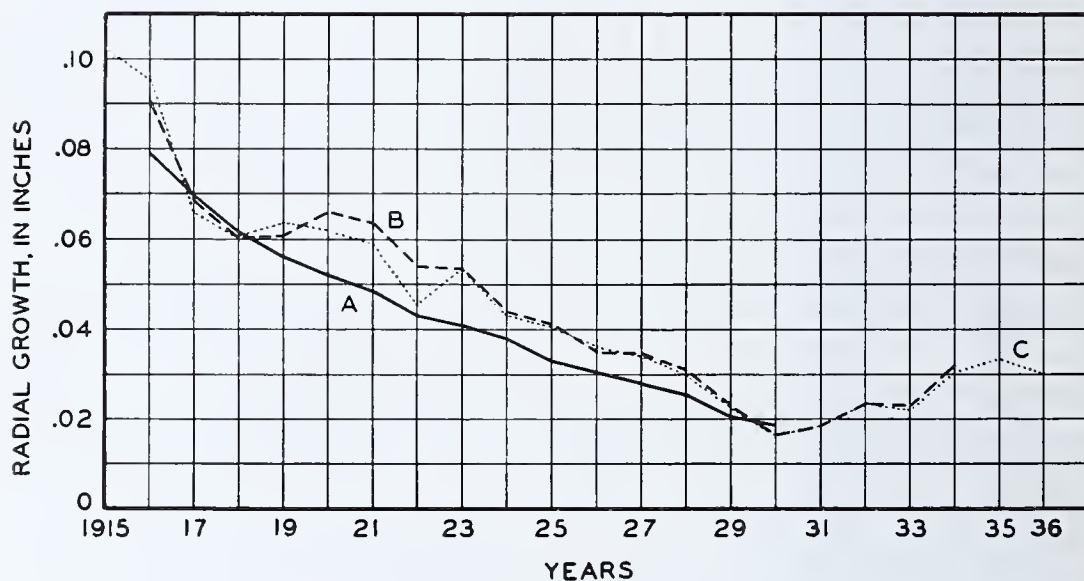


FIG. 25. Results of resampling Douglas fir.

A. 1930 (Groups 17 and 14).

B. 1934 (Groups 10 and 3).

C. 1936 (Groups 6 and 7).

but for the fact that the trees were much less exposed to fumes than were those, for example, of Group 8 for 1936, which showed complete recovery by 1935, and for the lack of corroborating evidence. The needles were sampled and analyzed for sulphur content in 1935, but the result merely confirmed the opinion that a limited amount of sulphur dioxide found its way to both of these groups. Only a little more than one mile from Group 7, and at but slightly

higher elevation, Group 6 of 1934 (Fig. 19) was growing vigorously in that year, with no evidence of retardation from sulphur dioxide. Further, in the immediate vicinity of Group 6, white pine, hemlock, cedar and grand fir trees, both old and young, were in excellent condition. While, therefore, there has probably been some effect of sulphur dioxide on both of these groups, the usual confirmatory evidence is almost wholly lacking, and some doubt must remain as to the principal cause of retardation.

In passing, it may be of interest to observe the result of resampling these groups, as shown in Fig. 25. It will be noted that the growth from 1916 to 1930, as shown in Curve A for 1930, is on the average about 0.005 in. per year lower than that of Curves B and C, for 1934 and 1936, which check almost exactly. This may be ascribed to the fact, as recorded in the 1934 field notes, that some of the trees bared in 1930 were dead by 1934. These trees, probably the most unthrifty even in 1930, were thus automatically eliminated from the later groups, and in their place thriftier trees were bared. On the whole, it may be said that the pictures are essentially the same.

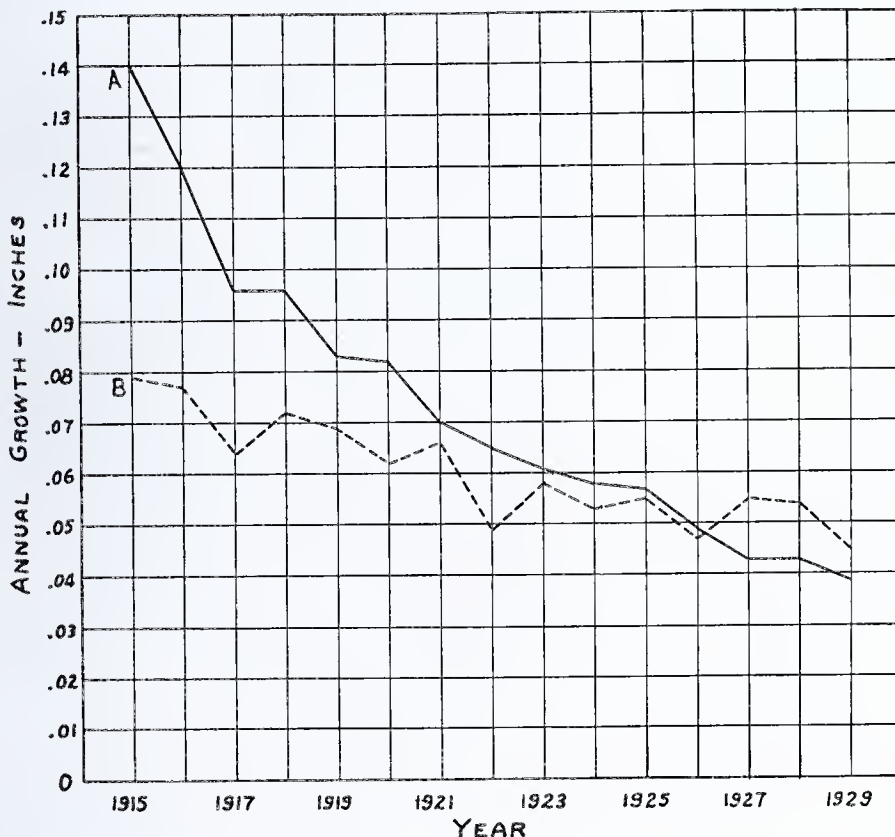


FIG. 26. Growth of lodgepole pine near International Boundary.
 A. Groups 5, 6 and 9 of 1929.
 B. Controls of 1929.

Effect of Sulphur Dioxide on Lodgepole Pine

As controls, 300 lodgepole pine trees, comprising Groups 1 to 4, east of Colville, were bored in 1929. Only the general direction of these groups is shown on the map.

Fig. 26 shows in comparison with these controls the growth of lodgepole pine Groups 5, 6 and 9, 208 trees situated within four miles of the Boundary on both sides of the Columbia and as close to the source of sulphur dioxide from Trail as a sufficient number of trees could be found. There is shown considerable retardation from the operation of both smelters, and it is quite possible that sulphur dioxide from Trail caused some retardation even during the operation of the Northport smelter. In spite of the effect of sulphur dioxide and drought, however, the trees maintained a growth of about 0.04 in. per year. This may be accounted for in part by the fact that the trees were quite young, the average diameter being only 6.75 in. in comparison with 6.58 in. for the controls and about 10 in. for most of the groups of yellow pine and Douglas fir.

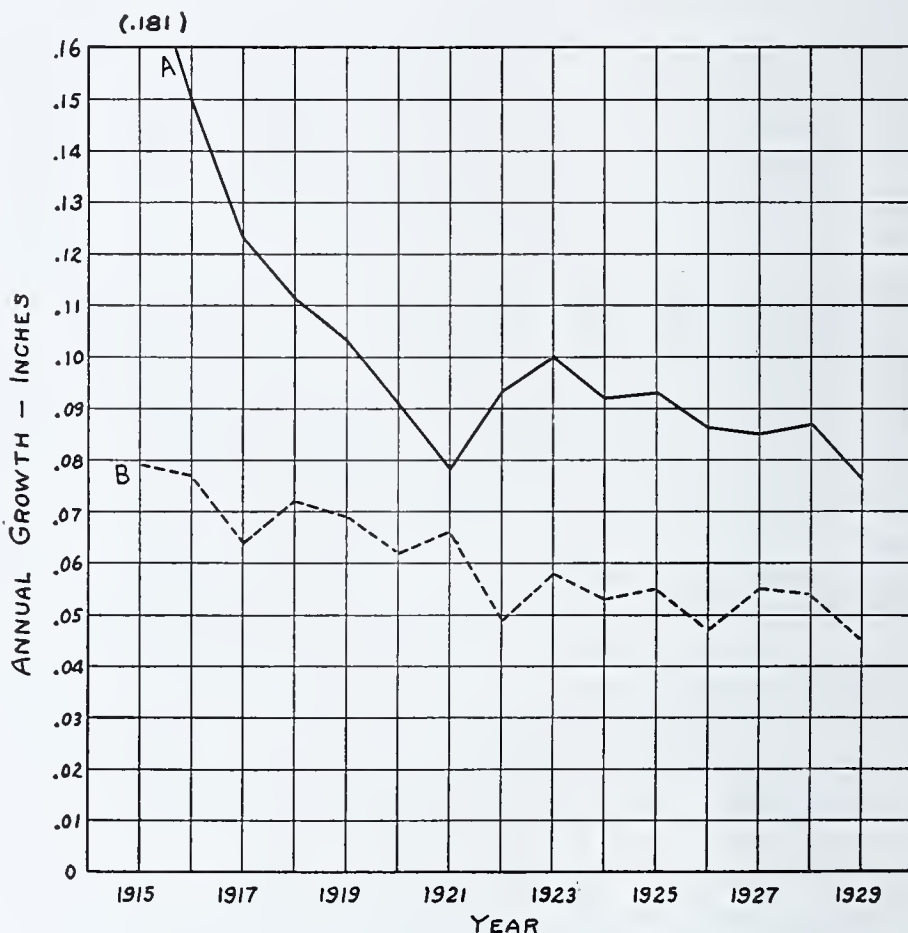


FIG. 27. Growth of lodgepole pine near Northport.

A. Groups 7 and 8 of 1929.

B. Controls of 1929.

In Fig. 27 there has been plotted the growth of 192 lodgepole pine trees in Groups 7 and 8, within three miles of Northport. These also were young trees, having an average diameter of 5.56 in. and showing vigorous growth throughout. The chart indicates that they were severely retarded by the sulphur dioxide from Northport until that plant was closed in 1921, when there was a prompt recovery with fully maintained growth until 1927, at which time a slight retardation, caused by fumes from Trail, became apparent.

Comparison of Species

It is not possible to make a direct comparison between the three species used, in respect to their sensitivity to sulphur dioxide, because in general the trees bored were in different groups, the Douglas fir usually being at a higher elevation. Taking this fact into consideration, the evidence suggests that Douglas fir is the most sensitive to the action of sulphur dioxide and that yellow pine is somewhat more sensitive than lodgepole pine. The growth of all three species has been substantially reduced in the area between Northport and the Boundary, where the effect of smoke from both smelters has been clearly observed. This effect has continued on a decreasing scale to Marble, beyond which point it is not possible to find any retardation as a result of the operation of the Northport smelter. That of the Trail smelter extends in a barely perceptible degree to the neighborhood of Bossburg, but is not detectable at Marcus. It may be noted that the Boundary, Northport, Marble, Bossburg and Marcus are distant from Trail along the course of the Columbia River about 11, 20, 28, 39 and 47 miles, respectively.

The greater effect of sulphur dioxide on diameter increment in the case of Douglas fir may be due to the weaker attachment of the needles, which sometimes fall after a mild fumigation, whereas the yellow pine needles are protected at their bases by sheaths formed by the bud scales, and remain on the trees even after a severe fumigation.

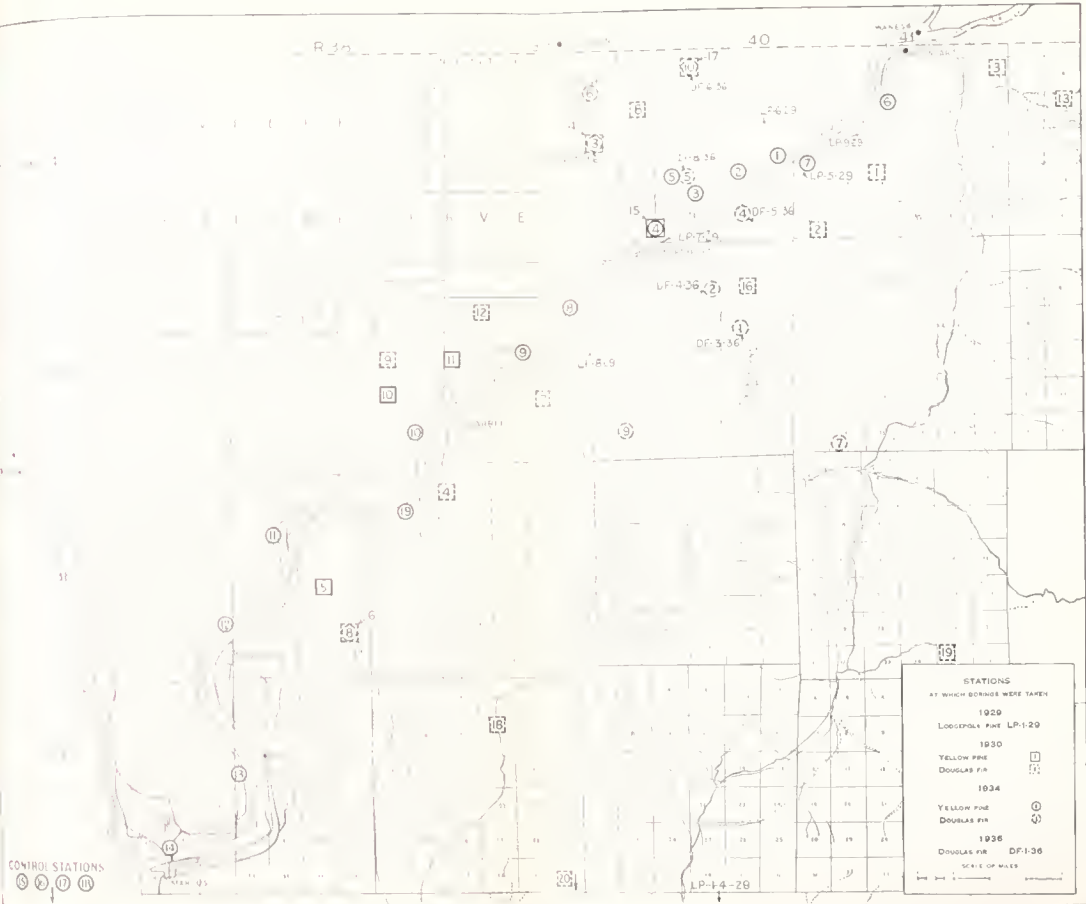
Attention has already been called to the fact that all the yellow pine groups, even in the immediate Columbia valley, had by 1932 fully recovered from the action of sulphur dioxide, while in one case the Douglas fir had not fully recovered even by 1936. The slower recovery of Douglas fir may be due not alone to their greater sensitivity to sulphur dioxide, but also to the fact that a normal tree carries several years' needles more than does a yellow pine. If, for example, Douglas fir and yellow pine growing together carry, on an average, seven and three years' needles, respectively, and are substantially defoliated by the action of sulphur dioxide or some other agency, it may be expected that they will not recover their previous rates of growth until they have again accumulated their full complement of needles, which will take four years longer in the case of Douglas fir than in that of the yellow pine.

A further factor in the delayed retardation of recovery of conifers is the storage of food in the needles, as a result of which they may continue to grow

for one season without appreciable retardation, even after adverse influences begin, and similarly at the close of a period of retardation they continue to lose ground for one season after the adverse influence has been removed. This explains the fact that the greatest retardation due to the operation of the Northport smelter frequently took place in 1921, even though the plant was closed in March of that year, and that the large increase in sulphur dioxide emission at Trail in 1926 did not ordinarily have much effect until 1927. It may also have a bearing upon the observed poor growth of controls in 1930 after the pronounced drought of 1929.

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PART II.
FUMIGATION EXPERIMENTS

CHAPTER VIII

DESCRIPTION OF PLOTS AND APPARATUS USED IN
EXPERIMENTAL INVESTIGATIONS

BY MORRIS KATZ, A. W. MCCALLUM, G. A. LEDINGHAM AND A. E. HARRIS

The experimental investigations on the effect of low concentrations of sulphur dioxide on conifers, barley, and alfalfa were carried out at the Dominion Experimental Station, Summerland, B.C., which is situated in the Okanagan Valley near the southwest end of Okanagan Lake. This site is about 150 miles west of Trail, and thus sufficiently distant from the smelter as to be indubitably in a sulphur-dioxide-free area but within easy access of the smoke zone by automobile.

Summerland is in a semi-arid region where fruits and other crops are grown under irrigation. The winter season is fairly mild, with light snowfall—about two feet—high winds, and very little sunshine. The summer is characterized by fairly high temperatures, low precipitation, and during the days, low relative humidity and high light intensity. The monthly mean temperatures over a 15 year period have been found to vary between a minimum of about 24.0° F. in winter and a maximum of about 70.6° F. in summer. The average annual precipitation is about 9.9 in. but in 1931 it was only 7.30 in. The winter of 1930-1931 was much milder than usual, with a snowfall of only 5½ in.

Experimental Plots

Conifer Plots, 1931

The site selected for these plots was on high land at the south end of the station about 600 feet above Okanagan Lake, or about 1700 feet above sea-level. There, on a bench with a northern exposure at the foot of a steep slope was a mixed stand of yellow pine and Douglas fir. Owing to the low precipitation in this area, tree growth is almost exclusively composed of yellow pine, but Douglas fir occurs wherever local moisture conditions are favorable. For this reason yellow pine was found to be generally scattered over the bench, whereas Douglas fir was confined to the lower part of the slope and to that part of the bench immediately adjacent, where soil moisture was higher on account of seepage and lower evaporation due to protection from direct sunlight. No other tree species occurred in this locality, so that the experiments were of necessity confined to yellow pine and Douglas fir.

In general, the young pines on this bench were in good condition, bearing about three years' leaves with a maximum of seven. Some young trees were found to have been killed by one of the blister rusts (*Cronartium comandrac*) and a few others were infected with this fungus. This rust is very destructive to young trees, although older individuals are able to resist its attack. It is a heteroecious form, having its alternate stage on various species of *Comandra*.

The fungus grows in the cambial region of the branch or stem, causing a fusiform swelling and finally girdling the tree. Aphid injury was found to be common, a considerable number of the pines showing some degree of this form of damage. Aphid injury was not very marked upon Douglas fir, and no disease caused by fungi was noted.

The plots were located in these natural stands of reproduction and were composed only of trees in good condition and relatively free from insect injury. The age of the trees varied from seedlings only a few years old to trees about 25 to 30 years old, and in many cases both seedlings and 15- to 20-year-old trees were located in the same plot. The plots in the earlier work were usually 6 ft. square but later, owing to a change in the type of cabinet used for this work, the plots were made 5 ft. square. In a few experiments however use was made of a cabinet covering an area of 144 sq. ft. The average number of trees in a plot was about 10 and the maximum 29. About 450 trees in 43 plots were treated.

Site of Irrigated Plots

These plots were established on two benches of the Experimental Station overlooking Trout Creek. Prior to their utilization for this work, these benches had been devoted to the growth of tobacco, clover and alfalfa. The soil is a moderately light loam, typical of the Okanagan bench lands. It is about two to five feet in depth and underlaid by a layer of gravel, two or three feet in thickness, which has originated as an outwash from higher levels. Underneath the gravel is the typical silt deposit that is characteristic of this district. The bench used in the experiments on barley in 1931 was situated about 75 feet above the bed of Trout Creek, whereas that utilized for the experimental work in 1935-1937 was about 150 feet above the creek. These benches have a gradual slope northward toward Trout Creek, the slope being somewhat steeper at the upper or south edge. The plots covered an area of about one acre in the central portion of each field.

Prior to the establishment of the plots, the land was carefully prepared by thorough cultivation in order to remove not only the top growth of the existing alfalfa but also the roots. A soil survey was carried out and the depth of the top soil determined at regular intervals over each field. The plots were then established over that portion of each field where the depth of top soil and texture were most uniform.

Barley Plots, 1931

The plots were arranged in parallel rows, the main plots being 6 × 6 ft. square, with a 3 ft. alleyway between two parallel rows. On both sides of these rows or ranges there was an 8 ft. space left for the setting up of the equipment used in fumigation, so that 8 ft. alleys were left between successive pairs of parallel ranges. In addition to the 6 × 6 plots, there were planted also six 12 × 12 plots for some long fumigation experiments.



FIG. 1. *A view of equipment used in fumigation experiments on conifers in 1931.*

The barley plots used in the yield studies were sown in May and June. The grain was planted by hand in rows 1 ft. apart, a 6 ft. plot consisting of six rows with a border space 6 in. in width. Since the rainfall in this semi-arid region is insufficient for adequate growth, the plots were irrigated. The early irrigation, that is, before the appearance of the coleoptile above the soil, was carried out by sprinkling. After the plants had reached a height of a few inches the water was applied through irrigation channels. The blank portion of the field was also irrigated in order to create uniform conditions. Soil moisture determinations were made as often as necessary and served as a guide for the irrigation. The soil moisture of the field was maintained as uniform as possible.

The total number of plots sown to barley was 153, the seed being a high grade of certified Hannchen barley obtained from the University of Saskatchewan. Of this number, some were used for yield studies and the remainder for experiments on the effect of various environmental factors on susceptibility to sulphur dioxide and the effect of this gas on the chemical composition of leaves and grain. In all, about 94 experiments were carried out on barley in 1931.

Alfalfa Plots, 1935-1937

During the years 1935-1937, alfalfa was the principal crop plant investigated but some experiments were carried out on barley in 1935. All the alfalfa plots were 6 × 6 ft. square and were laid out in double rows with a three-foot space between plots and 8 ft. alleys between each double row, as in 1931. Certified Grimm alfalfa was seeded in rows 1 ft. apart in August, 1934, and later in the autumn the plants were thinned to 15 in each row, thus making a total of 90 plants in each plot—in all 230 plots were established. The following April, 1935, the plants were counted and, wherever necessary, the gaps in the rows caused by winter killing were filled by transplanted seedlings of the same average height as the plants in the plot. The plants developed well during May and by June 1 a uniform stand was obtained.

- Before beginning the actual work on alfalfa in June, 1935, the plots were cut and weighed. It was established that the relative differences in weight between adjacent plots were quite small. By regulating the time of cutting of the ranges throughout the season, alfalfa at various stages of growth was always available for experimental purposes. The number of alfalfa plots was greater than could be experimented with in a given growing season, but this ensured an adequate supply of experimental material at all times. In addition, a number of barley plots were seeded in May, 1935, and winter wheat plots in October, 1934.

As in the case of the 1931 work the plants were supplied with moisture by irrigation. Sprinklers were used when the seedlings were small, but as soon as the plants were well established this system was discarded and the water allowed to flow in irrigation channels between the rows. The alfalfa plots were

generally irrigated once a week, but the application of water was governed by the results obtained from soil moisture determinations.

The most uniform alfalfa plots were set aside for yield and other agronomic studies, and investigations of carbon dioxide exchange; and the remainder was utilized for experiments on susceptibility under varied environmental conditions, the behavior of the stomata of the leaves and the relation between various sulphur dioxide treatments and some chemical constituents of the plant. A plan of these plots is shown in Fig. 1.

Conifer Plots, 1935-1937

These plots were established at the north end of the field, as shown in Fig. 1, in the autumn of 1934 and the spring of 1935. Seedlings and young trees of 11 species of conifers were obtained from the forest service nurseries at New Westminster, B.C., and Missoula, Montana, and from natural forest areas of the Okanagan, not far from Summerland. Douglas fir, yellow pine, lodgepole pine, and western larch were established without much difficulty, but only a small proportion of the white and silver fir, Sitka and Engelmann spruce, white pine, red cedar, and hemlock survived the effects of transplanting under conditions so radically different from those of natural habitat. The trees were arranged in plots 6 ft. square, generally nine trees to a plot.

Fumigation Equipment

The fumigation equipment consisted of six cabinets or plant chambers, three automatic sulphur dioxide recorders for the continuous measurement of sulphur dioxide in low concentrations, flowmeters of the capillary type for measuring out small quantities of sulphur dioxide from a small cylinder of the gas, mixing tanks, motors and blowers for maintaining a constant air movement through the cabinets, and portable humidifiers.

Cabinets

The cabinets measured 6 ft. square, with sides 50 in. high and a sloping top rising to an additional height of $1\frac{1}{2}$ ft. in the centre. The framework consisted of light iron plates and angles which were covered with a transparent celluloid material in sheets 20 in. by 50 in. The sheets were held in place by strips of felt and wood $1\frac{1}{2}$ in. in width, spaced about 18 in. apart, and conforming to the metal framework. The felt and wood strips were bolted and sealed to render the cabinets gas-tight. Each cabinet rested on a hollow rectangular, galvanized iron base 1 ft. high and 4 in. wide. In 1931 two cabinets, 12 ft. square and about 6 ft. in height were used, in addition to the 6×6 cabinets, but were discarded in favor of the smaller cabinets owing to the difficulty in moving plant chambers of such size. Mixtures of sulphur dioxide and air, after passing through a mixing tank, were admitted to the top of the cabinet

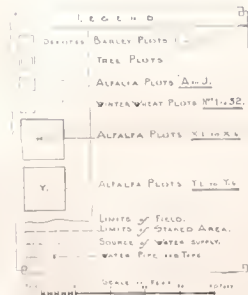
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through a 6 in. inlet pipe and discharged through openings in the inside wall of the base leading to an 8 in. vertical discharge pipe, 7 ft. high.

As most of the trees which were fumigated in 1931 were growing on sloping ground, it was necessary to build a frame support under the metal base of the cabinet to make it level. In this way additional height was gained and with the cabinets previously described it was possible to fumigate trees up to 7 ft. in height. Early in the spring of 1931 two additional cabinets were built especially for use in connection with the tree fumigations, the older cabinets being utilized in experiments on barley. These cabinets, which were 5 ft. square and of wooden construction, were divided diagonally into two halves so that they could be placed around the trees rather than over them. When set up the two halves were bolted together and covered with a one-piece top, which gave additional solidity. They were placed upon metal bases 2 ft. high and, as one cabinet was 7 ft. high and the other 8 ft., it was thus possible to enclose trees up to 10 ft. in height when the cabinet base was placed on the level; when it was set on a slope, one or two more feet could be gained.

Preparation of Mixtures of Sulphur Dioxide and Air

The synthetic mixtures of sulphur dioxide and air were prepared by passing sulphur dioxide, from a small cylinder equipped with a reducing valve, through a long capillary-tube flowmeter attached to an inclined manometer, and through a bubbler containing liquid petrolatum, into a mixing tank. The gas at a measured rate of flow was mixed in this tank with a large volume of air supplied by an electrically driven fan. The mixing tank was constructed of galvanized iron, $2 \times 1 \times 6$ ft., and it contained a series of staggered baffle plates. Air was passed into this chamber at the rate of about 200 to 250 cu. ft. per min. in the case of the small cabinets and 800 cu. ft. per min. for the large 12×12 cabinets. The sulphur dioxide cylinder, capillary flowmeter, manometer, and bubbler were enclosed in an insulated wooden box provided with an electric heater, water bath, and regulator, in order to maintain a constant flow of gas. The mixing tank was connected by means of 6 in. galvanized iron piping to the inlet pipe at the top of the fumigation cabinet. Measurements of the volume of air entering and leaving the cabinet were made at intervals by inserting anemometers at convenient points in the inlet and discharge pipes.

Sulphur Dioxide Recorders

A continuous record of the concentrations of sulphur dioxide at the intake and exit ends of the fumigation cabinet was obtained by the Thomas automatic recorders described in Chapter II. A portable apparatus of the type used in the atmospheric sulphur dioxide investigations was also employed on occasion to measure the concentrations of gas in the cabinets and to check the performance of the automatic recorders.

The automatic sulphur dioxide recorders were of two types. One of these machines was constructed so as to draw a sample of air continuously for 20 min. from one part of the cabinet, say, the intake, and at the conclusion of this half-cycle of operation, the source of the sample was changed automatically to the exit end of the cabinet. A complete cycle of operation in this case was 40 min., the absorbers being automatically drained and refilled with solution during this period.

In the case of the other two recorders, automatic readings were obtained of the intake and exit concentrations of gas every two minutes, the measurements being integrated seven times. Furthermore, two readings of two minutes each were obtained on samples of air drawn from the atmosphere of the field in the immediate neighborhood of the machine, so that a half-cycle of operation in this case lasted for 32 min. At the end of this period the source of the sample was reversed, the absorber which had been analyzing the intake concentrations of sulphur dioxide being switched to the exit and vice versa. The sulphur dioxide machine, during an experiment, was stationed as close to the fumigation cabinet as possible. The blank air sample drawn from the field during the four minute test, therefore, represented an analysis of the air in the vicinity of the control plot and served to show whether the air was contaminated appreciably by the exhaust gases of the fumigation cabinet. Large numbers of these tests were carried out but sulphur dioxide in detectable quantities could not be found.

Humidity

In the case of experiments conducted under high relative humidity conditions, the humidity of the air supplied to the cabinet was increased by connecting one or two portable humidifiers to the mixing tank and projecting a fine spray of water into the air entering the tank. For humidities above 70% it was usually found necessary to add saturated steam under low pressure from a small boiler, if the air velocity in the cabinet was maintained at 250 cu. ft. per min. The mixing tank served the purpose of entrapping large droplets of water carried in with the spray. The excess water was drained out by means of a stopcock provided for this purpose. Continuous measurements of the humidity and temperature were made by means of recording hygrothermographs placed inside the cabinets.

Sunlight Recorder

In 1931 the light intensity was determined by taking readings with a sensitive micro-ammeter connected to a photoelectric cell of the Burt type. Since 1935, however, the light measurements have been made by means of a recording potentiometer with a scale range of 0 to 50 millivolts, the circuit consisting of a photronic cell of the Weston type shunted across an appropriate resistance. The apparatus is calibrated by means of a standard high power lamp, and the

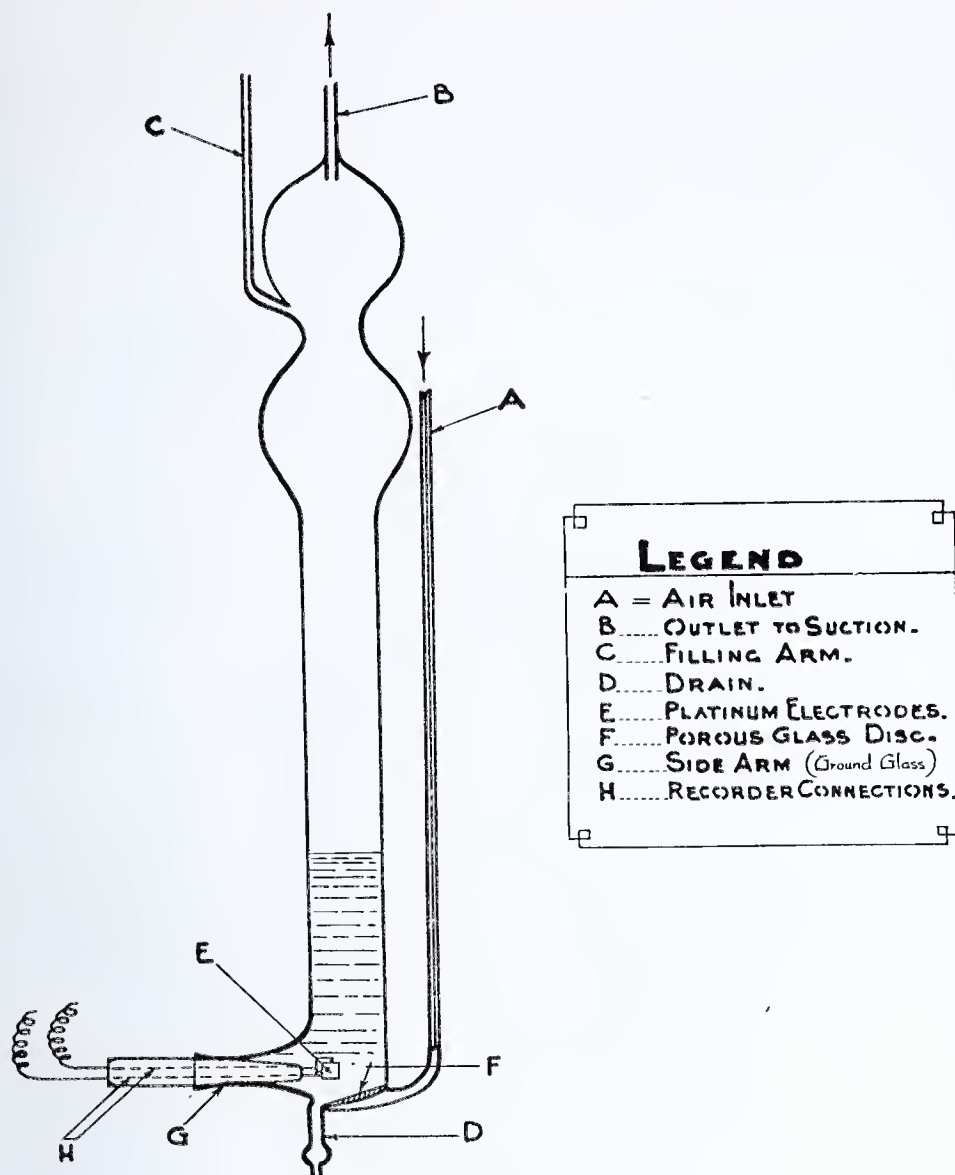


FIG. 2. Carbon dioxide absorber.

recorder readings may be converted directly into foot-candles. In practice the photoelectric cell was set up with the photosensitive surface towards the sky, so that the measurements obtained were those of average sky-light rather than direct sunlight. The average life of a cell under these conditions was about five weeks. The light intensity measurements showed good correlation with the observations on carbon dioxide exchange.

Automatic Carbon Dioxide Recorders

The apparatus used in making the measurements on photosynthesis and respiration of plants during this investigation consisted of two automatic machines adapted to the continuous measurement of atmospheric carbon dioxide. These were similar in construction to the apparatus described by M. D. Thomas (1, 2). Each machine contains two absorbers of the type represented in Fig. 2. The

absorber is fitted with a sintered glass disc through which the air sample passes in a stream of very small bubbles during the aspiration of the reagent, which consists of 0.0052 *N* sodium hydroxide, containing 0.25 to 0.40% normal butyl alcohol. Within these limits of butyl alcohol concentration and with a rate of aspiration of about 300 cc. of air per min. the efficiency of carbon dioxide absorption is 100%. This maximum efficiency is due to the smallness of the air bubbles when butyl alcohol is present, and to the large volume of foam, with its enormously increased absorbing surface, that develops with suitable rate of air flow. Before being placed in operation, each absorber is thoroughly tested for size and homogeneity of the bubbles produced, the resistance offered to the passage of the gas stream, the type of froth produced and the efficiency of absorption. The two absorbers in each carbon dioxide machine are mounted in a water bath equipped with accurate temperature control.

The air sample is accurately measured in a steel gas meter, consisting of two flat chambers connected by a U-tube, the whole being mounted on an adjustable pivot. Each chamber of the meter is connected by means of capillary glass and rubber tubing, to an absorber and also to the source of the air sample through appropriate valves. Mercury is added to the meter in sufficient amount to completely fill one chamber and the U-tube. The volume of air delivered by the meters used in this work was 640 cc.

In the operation of the machine the air sample enters one chamber of the gas meter from the outside source while air in the other chamber is being drawn through the fritted glass disc of one of the absorbers. The suction is adjusted by means of needle valves in the suction line of each absorber and also by a 2.5 litre bleeder bottle equipped with needle valves and attached to the pump. The carbon-dioxide-free air, after leaving the absorber, is passed through drying tubes of silica gel so as to prevent the deposition of small droplets of water in the needle valves and thus upset the suction on the system. In actual practice, the total air sample in the meter is drawn through one of the absorbers about ten seconds before the valve on the air line to the other side of the meter is opened. This ensures that the full air sample has passed through one absorber before the suction is applied to the other.

A complete cycle consists in the following operations. After fresh reagent has been automatically measured into the absorbers a sample of air is drawn through each absorber in turn for two minutes. The initial aspiration corresponds to a blank reading, as it serves, after the adjustment of the temperature of the solution, to establish an accurate zero point for the subsequent carbon dioxide measurements. The absorbers are then aspirated seven times alternately at two-minute intervals with air samples drawn from the intake or exit points of the cabinet containing the plant material. During this stage let us suppose that Absorber 1 is being aspirated with the air from the intake pipe of the cabinet and Absorber 2 with air from the exit pipe of the cabinet. During the two-minute interval in which the suction has been shut off from one absorber, and

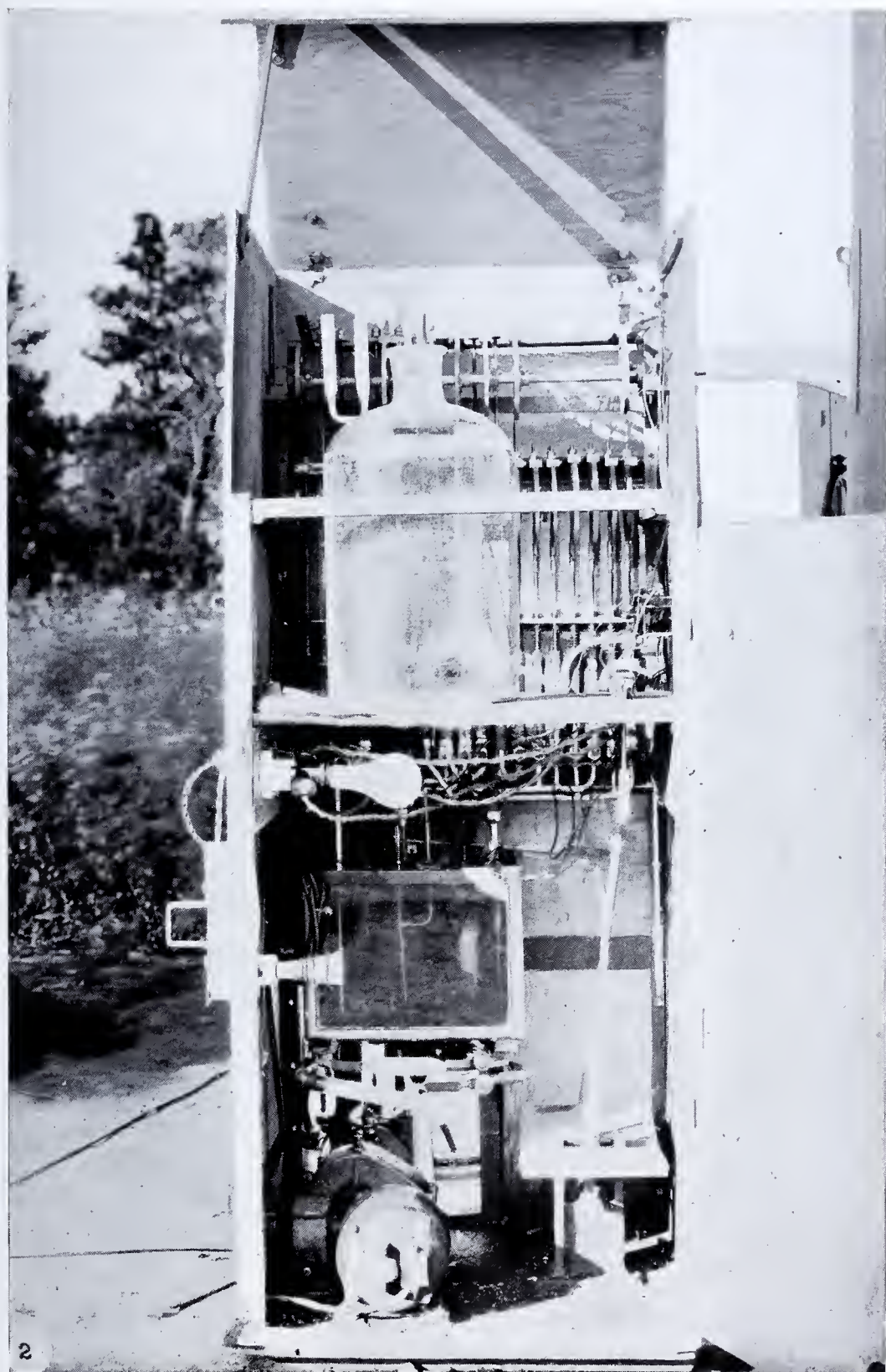
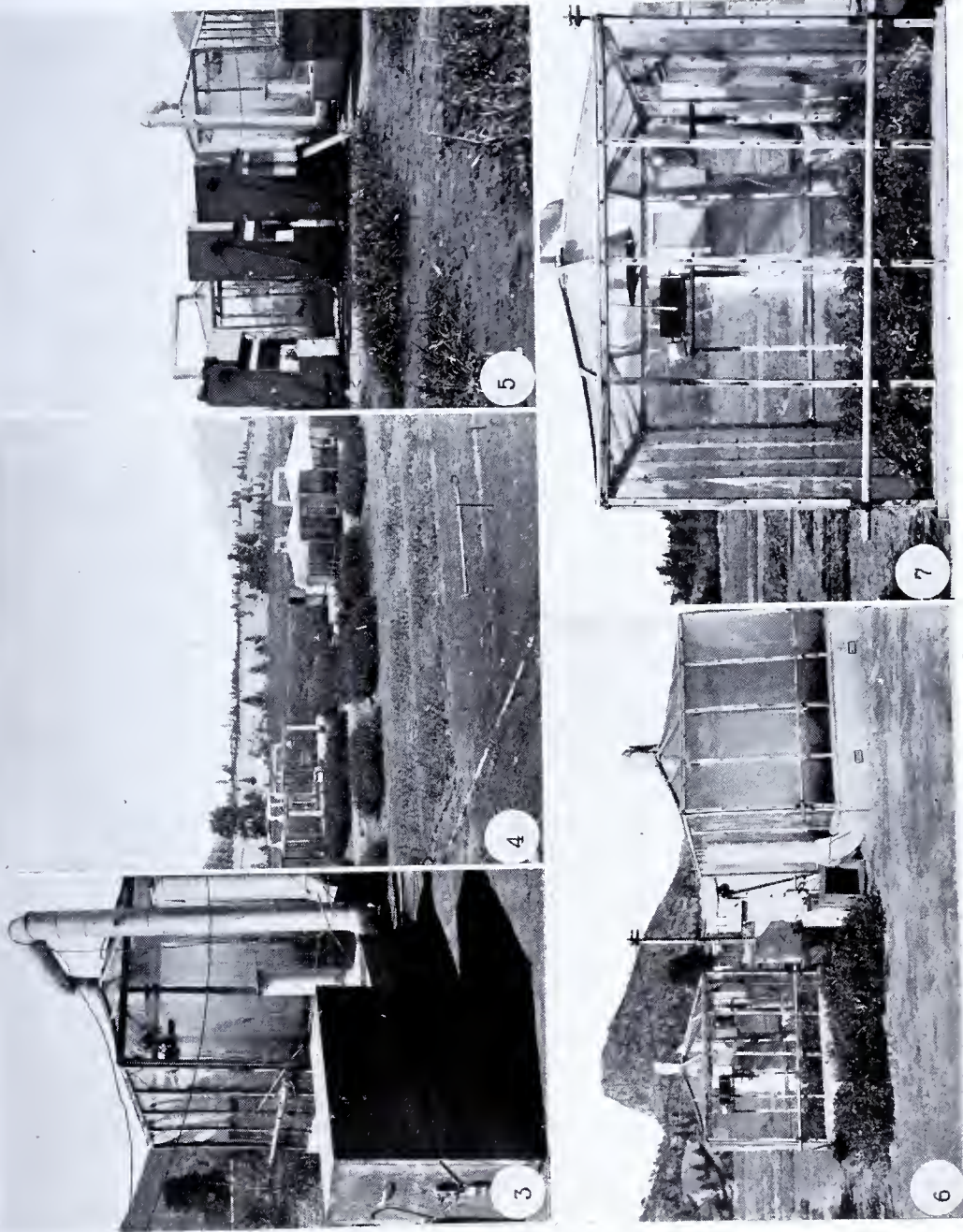


FIG. 2. *Automatic analytical machine for determining the rate of carbon dioxide exchange in experimental plant chambers.*

PLATE III



Views of field equipment. FIG. 3. Fumigation cabinet with insulated box, in foreground, containing temperature control apparatus for sulphur dioxide tank and flowmeter. FIG. 4. General view of cabinets placed over barley and alfalfa plots. FIG. 5. Control and fumigation cabinets, with one sulphur dioxide and two carbon dioxide machines. FIGS. 6 and 7. Further views of cabinets over alfalfa plots.

PLATE IV

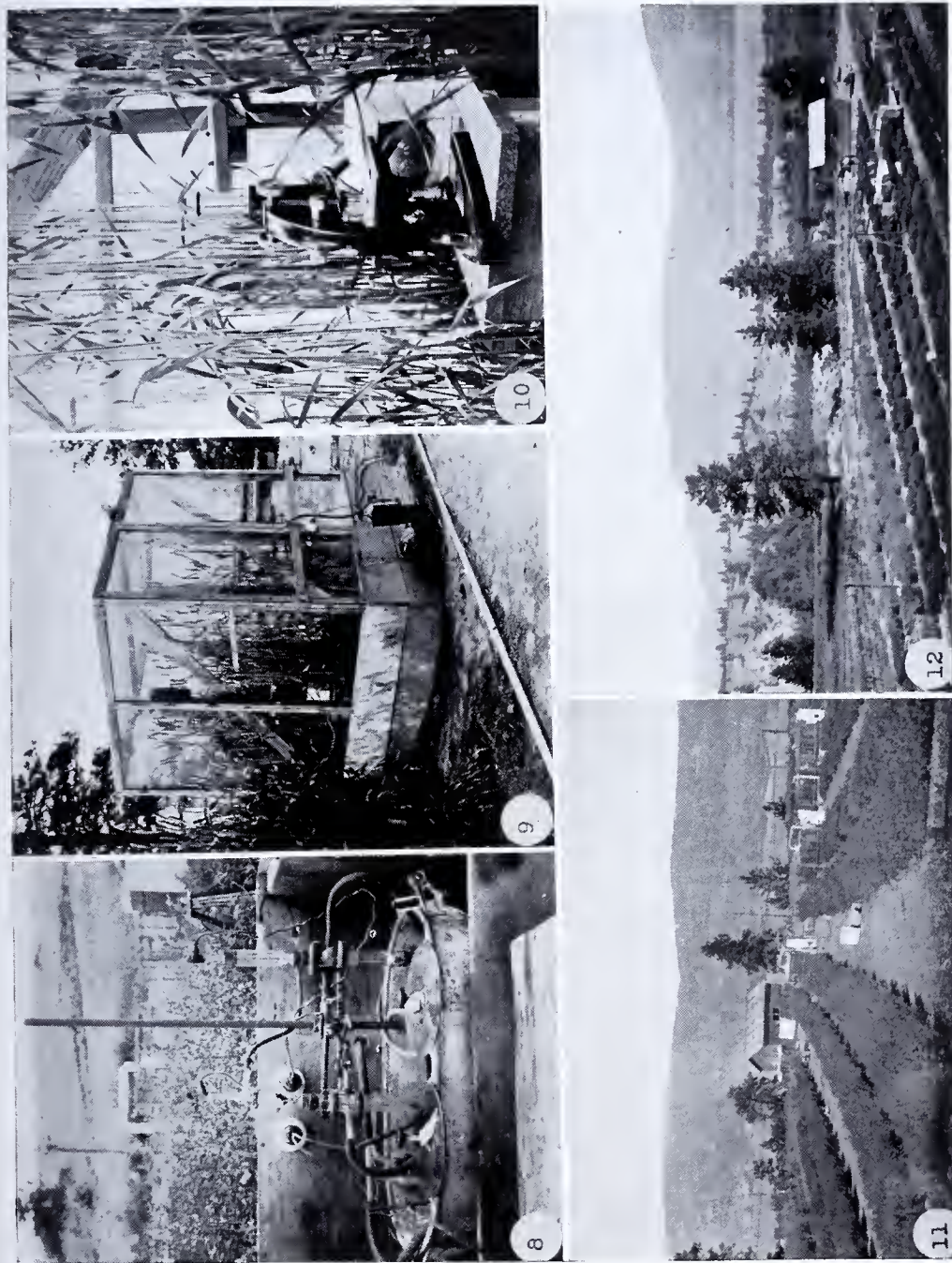
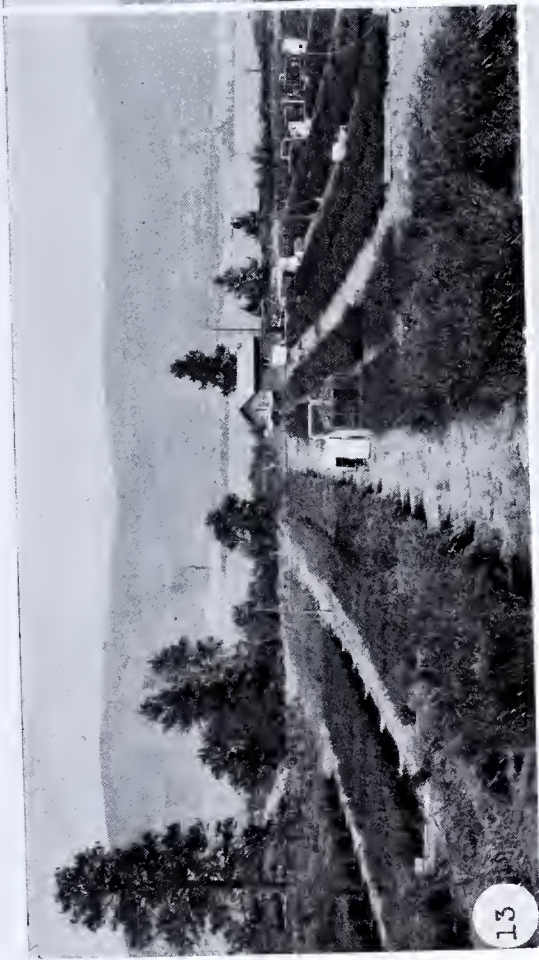


FIG. 8. Apparatus used in automatic measurement of stomatal changes in leaves. FIG. 9. Cabinet used as small field laboratory for microscopic observations on leaves. FIG. 10. Microscope in position for direct observations on stomata, without detaching leaves from plants. FIGS. 11 and 12. General views of plots.



FIGS. 13-16. General views of plots and equipment.

the liquid in it is quiescent, a record is obtained of the conductivity of the solution by means of a Leeds and Northrup recording Wheatstone bridge galvanometer. In this manner the recording galvanometer draws a curve indicating diminishing conductivity of the sodium hydroxide solution every two minutes in each absorber alternately. At the end of 32 min. the half cycle is completed, and the solutions are drained out of the absorbers, but not until the final record of conductivity has been registered. During the next half cycle the sequence of operations is the same, except that the source of the sample is now alternated so that Absorber 2 is being aspirated with air samples drawn from the intake pipe of the cabinet, and Absorber 1 with air from the exit. A complete cycle, therefore, takes 64 min.

The absorbers are calibrated by determining the extent of conversion of the sodium hydroxide to carbonate corresponding to definite readings of the recording galvanometer during aspiration with air. The titration method of Walker, Bray and Johnston, as adapted by Thomas (1), is employed to determine the amount of sodium hydroxide converted. The absorbers and electrodes must be calibrated for each temperature at which the machine is operated, i.e., the temperature at which the thermostat containing the absorbers has been set. The recording galvanometer has a range of 230 to 500 ohms for carbon dioxide work, and is equipped with a temperature compensator which is set to the same temperature as that of the thermostat containing the absorbers.

The carbon dioxide measurements were carried out in such a manner as to least disturb the normal environment of the plants during growth. The general experimental technique was similar to that used in the sulphur dioxide experiments, i.e., the plants were enclosed in cabinets which were supplied with a continuous stream of air and the quantity of carbon dioxide in this air stream was determined simultaneously at the points of inlet and exit. The air entered the cabinet at the top and escaped at the bottom through outlets placed in the galvanized iron base leading to an exit pipe. The intake of the fan supplying air to the cabinet was provided with a specially constructed shutter in order to vary at will the volume of air supplied to the cabinet. Measurements of the volume of air entering and leaving the cabinet were carried out by means of anemometers placed in the intake and exit pipes. Observations were also taken of the temperatures and humidities prevailing inside the cabinets. The fumigation cabinets were covered with transparent celluloid to allow free access of the plants to light. In carrying out a given experiment two plots were selected of similar age, appearance and size. These conditions were readily satisfied since all the alfalfa plots on the experimental field contained an equal number of plants. The control plot was subjected to the same environment with regard to the movement of air through the cabinet, soil moisture, humidity, temperature, etc., as the treated plot, and usually before the sulphur dioxide treatment was begun the comparative rates of carbon dioxide assimilation and respiration of the two plots were determined.

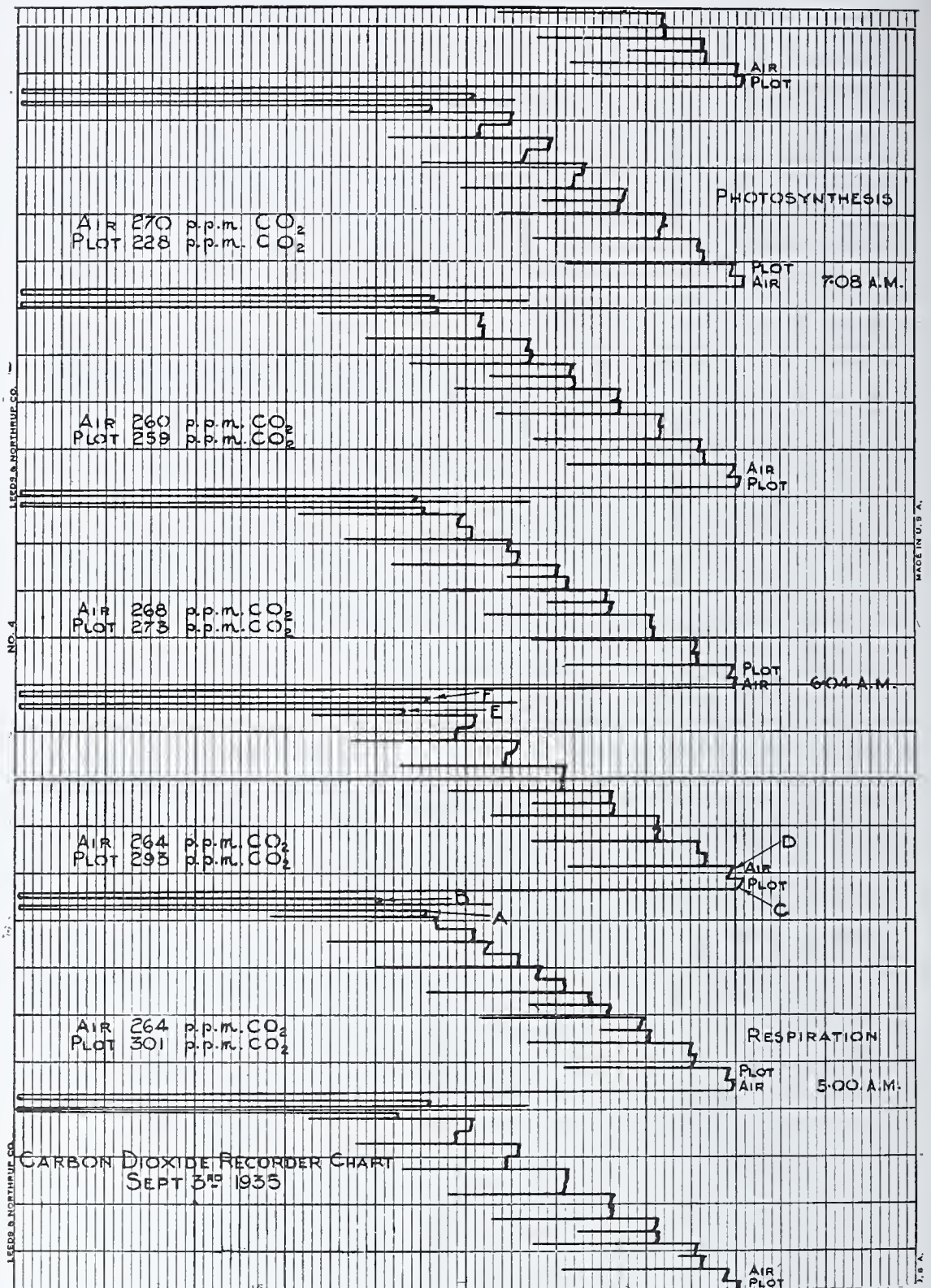


FIG. 3.

A section of a carbon dioxide recorder chart, for September 3, 1935, is shown in Fig. 3. The chart indicates that from 5.00 to 5.32 a.m. the average concentration of carbon dioxide in the intake air was 264 p.p.m. by volume, whereas the concentration of carbon dioxide in the exit air stream from the cabinet was 301 p.p.m. During the next 32 min., the concentration of carbon dioxide in the intake remained unchanged at 264 p.p.m, whereas the air leaving the cabinet now contained 293 p.p.m. carbon dioxide.

From the period 6.04 to 7.08 a.m. there was very little difference in concentration of carbon dioxide in the air entering and leaving the cabinet. During this hour, plant activity was gradually changing from respiration to photosynthesis. The chart indicates clearly that during the interval 7.08 to 7.40 a.m. the plants absorbed carbon dioxide from the air. Throughout this cycle the intake air contained 270 p.p.m. of carbon dioxide, whereas the exit reading dropped to 228 p.p.m.

Referring again to the chart in Fig. 3, the conductance of the solution in Absorber 1 is shown at Point A, after seven successive aspirations of two minutes each with air drawn from the atmosphere. Similarly, the conductance of the solution after an equal number of aspirations with air drawn from the plot is shown at Point B. Points C and D show initial readings of the fresh solution, the liquid in the two absorbers having been automatically drained and refilled during the interval. A reversal of the source of sample has also been automatically effected. Absorber 1, which was previously aspirated with air drawn from the atmosphere, is now being aspirated with air drawn from the plot. Conversely, Absorber 2 is now being aspirated with air from the atmosphere. Points C and D on the chart represent blank readings. Points E and F indicate the final conductivity of the solution in Absorbers 1 and 2 respectively.

The readings obtained every 32 min. were averaged and the hourly rates of carbon dioxide assimilation or respiration calculated in grams per plot. The measurements showed only slight variations for a given pair of plots unless the carbon dioxide exchange was upset by the presence of sulphur dioxide.

In the experiments made in 1935 the factor of soil respiration was neglected, it being assumed that the respiration of the soil in two similar plots would not be appreciably different. In the 1936 and subsequent experiments, however, the soil respiration was measured directly by use of a third cabinet placed over a blank plot from which the alfalfa had been cut, leaving only the roots. The cabinet was shaded and the soil moisture of the blank plot maintained comparable to that of the control and fumigated plots. The soil respiration was thus taken into account in the calculation of the rates of carbon dioxide exchange of the plants.

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CHAPTER IX

FUMIGATION EXPERIMENTS ON CONIFERS IN
THEIR NATURAL HABITAT

BY MORRIS KATZ AND A. W. McCALLUM

Introduction

Experiments on the effect of sulphur dioxide on conifers were undertaken in 1931 at Summerland, B.C., in order to supplement the investigation of smelter fume damage to trees in the vicinity of the smelter at Trail, B.C. The determination of injury to conifers in the field is greatly complicated by the occurrence of symptoms similar to those produced by sulphur dioxide but due to other causes. Among these the principal ones are winter killing and drought injury. Discolorations on coniferous foliage caused by winter injury were found to be present to some degree each year in the area affected by the operations of the Trail smelter as well as in contiguous areas outside the zones of sulphur dioxide occurrence. It became a matter of great importance to determine whether conifers were also injured by sulphur dioxide during the winter season.

The studies at Summerland, B.C., were also concerned with the susceptibility of conifers to specific sulphur dioxide concentrations, the seasonal variation in susceptibility, and the relation between extent of absorption of sulphur dioxide and injury. Observations were made in order to determine progressive, cumulative and residual effects. The experiments were carried out under conditions similar to those obtaining in the field, using yellow pine and Douglas fir trees growing in natural habitat rather than transplanted stock or greenhouse plants.

In the selection of plots for fumigation, trees in good condition and standing close together were chosen, as it was considered desirable to have a sufficient number of trees in each plot to allow for individual variations in susceptibility. As the site selected for the experiments was a natural stand of reproduction the grouping and arrangement were not always the most desirable, but it was generally possible to locate satisfactory plots of both pine and fir. The largest plot fumigated covered an area of 144 sq. ft. and contained 29 trees, while the average number of trees in a plot was 10. In all, 40 plots, containing a total of about four hundred and twenty trees, were treated. The age of the trees varied from seedlings only a few years old to those about twenty-five to thirty years old, and it was possible in many cases to secure both seedlings and 15- to 20-year old trees in the same plot. Also it was considered advisable, wherever possible, to include both Douglas fir and yellow pine in the same plot.

Before the fumigation cabinet was placed over a particular plot, a careful examination was made of the condition of the foliage on the trees in the plot. Any discolored leaves were either removed or their position on each tree was

carefully noted. Samples of green foliage were taken for sulphur analyses, the first four years' growth of fir and the first three years' growth of yellow pine being analyzed separately. Each tree in the plot was numbered by affixing a metal tag, and observations of its condition were made during treatment and for some months subsequently.

Experimental work was begun on January 27, 1931, and was continued until about the end of September of that year. Concentrations of sulphur dioxide were maintained as nearly constant as possible during a given experiment, and usually for a duration sufficient to cause the first appearance of sulphur dioxide injury. In certain cases, however, the trees were fumigated at a fixed concentration for a definite period of time regardless of whether injury took place or not. The concentrations were varied in the different experiments from 0.25 to 5.00 p.p.m., but one plot was fumigated at a concentration of 20.00 p.p.m.

Literature Review

A review of the literature indicates that, although there are numerous references to sulphur dioxide injury to trees growing in the vicinity of smelters and industrial plants, there are few instances of the experimental fumigation under controlled conditions of transplanted trees and fewer still of trees growing in natural habitat. The early investigations of Stockhardt, Schroeder and Schmitz-Dumont (5), Reuss (5), Wieler (10), Haywood (3, 4) and Stoklasa (6) suffer from the limitations imposed by unnatural environmental conditions, lack of proper apparatus, insufficient air movement through the experimental cabinet, static conditions, and also inexact knowledge of the concentrations of gas prevailing inside the cabinet. For these reasons most of these early results on susceptibility of conifers to sulphur dioxide must be accepted with reserve. In general, the concentrations used were very much higher than those found in industrial areas.

Wislicenus (11, 12) was among the first to recognize the limitations of the early work, and for his later experiments built a special greenhouse, equipped with ventilators and supplied with air by electrically operated fans at about 10 cubic metres per minute, the greenhouse having a capacity of 67 cubic metres. Improvement was also effected in the manner of making up the sulphur-dioxide-air mixtures, the gas being supplied from a tank containing liquid sulphur dioxide, equipped with reducing valves, needle valves, and manometer, rather than by burning sulphur as in the older experiments. Although some difficulty was experienced by Wislicenus in maintaining the required gas concentrations uniformly through the greenhouse, nevertheless, with this greatly improved experimental technique, he found the conifers to be far more susceptible to sulphur dioxide gas during the active growing period than in previous experiments.

Wislicenus found that the needles of conifers are most susceptible to sulphur dioxide during the period of active assimilation in the summer. During the

dormant winter period, at night, and in artificial darkness, the conifers are least susceptible to sulphur dioxide. Of the conifers, the pine was found to be most resistant, and spruce, the least. In the transition period from winter to summer, the susceptibility of the needles was found to increase with the progressive building up of the young leaf organs. The young needles in the spring, prior to their full development, were not affected by concentrations of 1 to 2 p.p.m. of sulphur dioxide. All these experiments were carried out on potted plants, the conifers varying in age from young plants several years old to plants about 16 to 20 years old.

Recently Beran and Reckendorfer (1) carried out some experimental fumigations with three-year-old spruce set out in a small plantation in the grounds of the Institute for Plant Protection at Vienna. These were treated under a cabinet with concentrations of 10 p.p.m. for periods of two hours each day. After five to six days most of the trees showed the first symptoms of injury, the leaves having become paler in color; after 8 to 12 days considerable injury was noted; and after 18 days the trees were completely discolored. The foliage was analyzed for sulphur trioxide content after 6, 12 and 18 days. Only a slight increase in sulphur content was shown.

Wieler (9), in his recent investigations, reports on the effect of dilute concentrations of sulphur dioxide on a number of coniferous species grown in plots in a garden. This investigation was concerned with the question of "invisible injury", and studies were made of the percentage loss in carbon dioxide assimilation after fumigation. The plants growing in the garden were fumigated in the open. Sulphur dioxide from a large cylinder was measured out by means of a flowmeter, mixed with the required amount of air from a fan, and then blown through a galvanized iron, rectangular mixing tank, the open end of which was directed towards the plants. The whole apparatus was mounted on a movable truck or platform and set up in the vicinity of the trees to be fumigated. The mixture of sulphur dioxide and air was therefore blown over the surface of the plants and the concentrations in the vicinity of the plants could not be known exactly. The plants nearest the apparatus would receive the highest concentrations of gas. The fumigation experiments were carried out with red beech, oak, birch, spruce, pine and larch.

Wieler (8) noted the seasonal variation in susceptibility of conifers. In September and October of 1932, spruce was fumigated for 35 to 64 hr. with concentrations of one part in 500,000 to one part in 150,000, without any injury whatever. In August also a 60 hr. fumigation with concentrations of one part in 750,000 to one part in 500,000 had no effect. On the other hand, 50 to 60 hours' fumigation in June and July with concentrations of one part in 500,000 produced injury on the young leaves. In the case of pines, potted plants being used as experimental material, a fumigation for 100 hr. with a concentration varying between one part in 375,000 to one part in 750,000 caused slight injury during June. With similar concentrations of gas, injury resulted from a 40 hr.

fumigation in July. In the autumn months of September and October, 64 and 80 hr. fumigations with one part in 500,000 and one part in 375,000, respectively, were without effect, and during the winter month of December the plants showed no injury after fumigation for 50 hr. with one part in 100,000. Larch was found to be extremely susceptible to sulphur dioxide. Pronounced injury was obtained after fumigating larch for 30 hr. with a concentration of one part in 750,000 in early June. A fumigation of similar duration with three times this concentration in October resulted in a lesser degree of injury.

Susceptibility of Conifers to Sulphur Dioxide

Broadly speaking the seasonal variation in susceptibility of coniferous trees may be divided into two periods, a susceptible period which coincides with the time of the year when active growth is taking place and a resistant period corresponding to the time when the trees are in a dormant condition and show little signs of activity or growth.

Owing to the mildness of the winter at Summerland during 1931, the dormant period may be considered to have ended early in March. During March the conifers became quite susceptible to sulphur dioxide when compared with the preceding month. The temperatures during the fumigation experiments in March were quite often higher than 40°F. during the day. In August and September, on the other hand, the susceptibility of the conifers to sulphur dioxide decreased quite rapidly in spite of the relatively higher temperatures which prevailed.

The effect of sulphur dioxide concentrations between 4.00 and 5.00 p.p.m. is shown in Table I. It would appear that at a concentration of 5.00 p.p.m. the limiting duration for injury is about 14 hr. during the period of the year when the trees are most susceptible to sulphur dioxide. Longer fumigations were decidedly injurious during the early spring and summer.

The plots of trees were re-examined in August 1934 in order to observe the residual effect of fumigation. The most pronounced effect was noted in the case of Plot 30 (Table I) in which the trees had sustained injury to nearly all the foliage during treatment. In 1934 it was noted that the two pines had been killed by the fumigation, whereas the firs carried a scanty growth of from two to three years' leaves and resembled very much those firs which occur in the valley of the Columbia River near the International Boundary. There had been a partial killing of the limbs, and the leaves were principally confined to the interior of the tree, *i.e.*, along the main stem and the inner parts of the branches. Adventitious buds had formed along the main stem and on the adjacent parts of the limbs. This plot was unquestionably the most severely injured of the whole series, and its condition indicates the drastic effect of fumigations with such high concentrations during the growing season.

TABLE I
EFFECT OF SULPHUR DIOXIDE CONCENTRATIONS BETWEEN 4.00 AND 5.00 P.P.M.

Plot No.	Number of trees	Duration	Temperature °F.			Humidity %			Weather	Result of treatment, 1931		Condition of plot, 1934, residual effect
			Max.	Min.	Av.	Max.	Min.	Av.		Estimated percentage injury to foliage		
At 4.00 p.p.m.												
2	5 yellow pine 9 Douglas fir	168 hr. Feb. 4-11	38	24	31	98	60	80	Cloudy. Low light intensity throughout most of fumigation period	90 % of foliage injured Severe injury on all trees	Slight	
At 4.70 p.p.m.												
41	5 yellow pine	216 hr. Aug. 31-Sept. 9	82	46	63	94	34	51	Dull and cloudy throughout most of fumigation period. Bright sunshine on Sept. 7, only	35 % of foliage injured. The first symptoms of injury appeared after 41 hours' fumigation	Slight	
At 5.00 p.p.m.												
5	6 yellow pine 6 Douglas fir	96 hr. Feb. 12-16	37	21	30	96	56	89	Dull and cloudy throughout most of fumigation period. About 10 hr. of sunlight	Trace. A few leaves on one branch of one Douglas fir showed injury	None	
12	8 yellow pine 15 Douglas fir	120 hr. Mar. 3-8	38	26	33	90	34	61	Cloudy on March 4. Bright sunlight or clear on remainder of days	90 %. All trees injured	Severe	

TABLE I—Continued

Plot No.	Number of trees	Duration	Temperature °F.			Humidity %			Weather	Result of treatment. 1931		Condition of plot, 1934, residual effect
											Estimated percentage injury to foliage	
14	17 yellow pine 13 Douglas fir	45 hr. daytime only, Mar. 12-17	54	36	47	74	32	55	Clear on March 12. Partly cloudy March 13-16. Clear on March 17	80%. All trees injured, 22 severely so	Slight	
30	2 yellow pine 8 Douglas fir	40 hr. June 29-July 1	78	44	60	75	30	51	Cloudy on June 29. Intermittent sunlight June 30, Clear July 1	100%. All trees very severely injured	Severe	
32	2 yellow pine 6 Douglas fir	19 hr. July 6-7	89	60	74	62	23	48	Clear, bright	65%. Both yellow pine and Douglas fir severely injured. First symptoms after 14 hr. treatment	None	
37	1 yellow pine 2 Douglas fir	9 hr. July 28	88	69	81	55	7	24	Clear, bright	None	None	
38	1 yellow pine 3 Douglas fir	14 hr. July 30	96	71	86	43	15	26	Partly cloudy	None	None	
At 20.00 p.p.m.												
3	12 Douglas fir	14 hr. intermittent, Feb. 11-12	38	24	31	98	90	95	Intermittent sunlight, Feb. 11, cloudy Feb. 12.	None	None	

In only two other experiments were trees actually killed by treatment with sulphur dioxide. In Plot 2, two small pines were killed. One of these had already been injured by rust and the other was a seedling, 6 in. in height. In spite of the fact that the remaining trees were severely injured by the gas treatment, the plot, as a whole, had made a marked recovery by 1934. The other case was in Plot 12. One yellow pine died as a result of the fumigation while the remainder of the trees did not carry the usual number of years' leaves, and were growing slowly.

As in the case of the experiments with 5.00 p.p.m., concentrations of 2.00 p.p.m. were also found to be distinctly injurious to Douglas fir and yellow pine except during the dormant period. With these high concentrations the effect on the trees, in experiments carried to the point of visible injury, was rather different than in the case of lower concentrations. Usually when the fumigations were carried out at lower concentrations and the experiments were stopped at the first sign of injury, the resultant damage would be very small, affecting only a few leaves out of the thousands on the trees. With 2.00 p.p.m. or higher the proportion of injured leaves was quite large, at least one leaf out of every three or four on the plot being discolored. The collapse and death of the plant tissue with these higher concentrations was quite sudden.

As shown in Table II conifers were not injured after 69 hr. of continuous treatment with 2.00 p.p.m. in February, but a month later (towards the end of March, see Plots 15 and 16) 35 hr. of fumigation, extending over a period of four days, during the daytime only, was sufficient to destroy 75% of the foliage on a plot. At this time the trees were transpiring actively as a result of favorable weather conditions and the early advent of spring. In two experiments carried out in March with a concentration of 2.0 p.p.m., one of which was carried on in the daytime and the other at night only, it required about eight additional hours of gas treatment to injure the trees in darkness to about the same extent as those fumigated in daylight. The effect of light, although noticeable, was not as pronounced as one would expect.

As shown in Table II, there was a noticeable residual effect on Plots 9, 15, 16, 31, and 42 in August, 1934—about three years after the gas treatments. Plots 15 and 16 showed a very substantial recovery from the sulphur dioxide treatment, the only visible effects at this time being a thinness of foliage on some trees. Plot 31 did not show as good a recovery as Plots 15 and 16, although injured to a lesser extent in 1931. The fact that Plot 31 was treated during July, at a time when the current year's growth was substantially complete, may have had something to do with the greater retarding effect in this case, since the injuries received would interfere with the storage of carbohydrate reserves for the following year's growth to a greater extent than in the trees fumigated in March. The pines in Plot 31 were retarded to a lesser extent than the firs. Plot 9, which was very severely injured in 1931, showed a severe residual effect or retardation in growth. In 1934 the foliage was noticeably scanty. Plot 42,

TABLE II
EFFECT OF SULPHUR DIOXIDE CONCENTRATIONS BETWEEN 1.50 AND 2.00 P.P.M.

Plot No.	Number of trees	Duration	Temperature °F.			Humidity %			Weather	Result of treatment, 1931, estimated injury to foliage	Condition of plot, 1934, residual effect
			Max.	Min.	Av.	Max.	Min.	Av.			
At 1.50 p.p.m.											
35	3 yellow pine 4 Douglas fir	150 hr. July 16-22	96	52	72	91	13	49	Clear, bright, during daylight hours	10%. Only one Douglas fir injured. First symptoms appeared on current year's leaves after 143 hours' treatment	None
At 1.60 p.p.m.											
28	2 Douglas fir	120 hr. June 15-20	75	46	62	94	30	70	Dull, cloudy during June 15-19, clear, bright on June 20	40%. Both trees moderately injured. First symptoms appeared on current year's leaves after 84 hours' treatment	None
42	5 yellow pine	142 hr. Sept. 10-16	64	46	54	94	36	74	Dull or cloudy on September 10-14 and 16. Clear, bright on September 15	20%. One tree uninjured, two slightly, and two moderately injured. First symptoms appeared on current year's leaves after 120 hours' treatment	Slight

TABLE II—Continued

Plot No.	Number of trees	Duration	Temperature °F.			Humidity %			Weather	Result of treatment, 1931, estimated injury to foliage	Condition of plot, 1934, residual effect
			Max.	Min.	Av.	Max.	Min.	Av.			
At 2.00 p.p.m.											
7	6 yellow pine 6 Douglas fir	69 hr. Feb. 17-20	48	34	41	94	45	74	Clear, February 17. Cloudy or dull, February 18-20	None	None
9	6 yellow pine 1 Douglas fir	144 hr. Feb. 24-Mar. 3	46	29	37	97	60	81	Cloudy, February 24- March 2. Clear, March 3	90%. All trees severely injured	Severe
15	10 yellow pine 12 Douglas fir	43 hr., night only Mar. 18-23	46	32	40	92	48	75	—	70%. All trees injured but one Douglas fir	Slight
16	24 yellow pine 5 Douglas fir	35 hr., daytime only Mar. 19-23	56	38	44	92	25	68	Cloudy on March 19. Partly cloudy, March 20-22	75%. All trees injured	Slight
31	4 yellow pine 2 Douglas fir	48 hr. July 1-3	88	56	69	79	15	41	Clear, bright on July 1 and 3. Intermittent sunshine, July 2	40%. All trees moderately injured	Medium

on the other hand, which suffered injury to the extent of 20% of its foliage, showed only a slight residual effect, the quantity of foliage on the trees in 1934 being only slightly less than that on nearby control trees.

Nine experiments were carried out with average concentrations of 1.00 p.p.m. and one at an average concentration of 1.25 p.p.m., as shown in Table III. During February, Douglas fir and yellow pine fumigated with concentrations of 1.00 p.p.m. showed no signs of injury after 113 hours' continuous treatment, only slight injury after 120 hr. and about 5% injury to the foliage after 168 hr. In June the first symptoms appeared after 110 hours' fumigation in one experiment (Plot 25), whereas in another experiment there was no effect after 144 hr. In July and September there was no effect produced by continuous fumigations of 220 hours' and 198 hours' duration, respectively. With 1.25 p.p.m., during July, the first symptoms appeared after 92 hr., but there was present only slight injury involving 5% of the foliage after 120 hr.

In none of these experiments was there evidence of a visible residual effect in August of 1934. The trees were in a thriving condition and not noticeably different as regards density and color of foliage from the surrounding controls.

The data in regard to experiments with average concentrations of 0.25 to 0.75 p.p.m. are given in Table IV. In five out of six experiments with concentrations of 0.75 p.p.m. the sulphur dioxide treatments proved innocuous, but in one experiment about 55% of the tree foliage was injured after 147 hr. during the period March 26 to April 1 (Plot 19). From the data in Table IV it is evident that conifers are more susceptible to gas at the end of March and early April than in late August.

The trees in Plot 19 showed a medium residual effect in August 1934. The color of the needles was a yellowish-green compared with the controls and their foliage was rather scanty. In none of the other plots in Table IV was there any noticeable evidence of a residual effect.

It was found that concentrations of 0.25 p.p.m. could be maintained continuously for 450 hr. without causing any injury to pine and fir at the most susceptible period of the year. Also in experiments with concentrations of 0.50 p.p.m. a continuous fumigation of 336 hours' duration in March resulted in only a trace of injury to yellow pine. In the autumn (August 14 to September 25) an experiment was carried on for 1008 hr. with similar concentrations without the appearance of visible symptoms of injury. There was no apparent residual effect in any of the plots fumigated with concentrations of 0.50 p.p.m. or lower.

The greatly increased resistance of conifers to sulphur dioxide gas in the autumn and winter is clearly related to the decreased physiological activity of the needles at this time of the year. According to Weaver and Mogensen (7) the transpiration of conifers decreases markedly from autumn to winter and in

TABLE III
EFFECT OF SULPHUR DIOXIDE CONCENTRATIONS BETWEEN 1.00 AND 1.25 P.P.M.

Plot No.	Number of trees	Duration	Temperature °F.			Humidity, %			Weather	Result of treatment, 1931, estimated injury to foliage	Condition of plot, 1934, residual effect
			Max.	Min.	Av.	Max.	Min.	Av.			
At 1.00 p.p.m.											
1	2 yellow pine 11 Douglas fir	120 hr. Jan. 27-Feb. 3	42	30	35	98	70	89	Cloudy throughout entire fumigation period	2%. Slight injury to three Douglas fir	None
6	8 yellow pine 11 Douglas fir	113 hr. Feb. 14-20	48	21	36	96	45	80	Cloudy on mornings of February 14, 15, 16 and 18. Clear in the afternoon periods. February 17 and 19, clear with sunlight, February 20, cloudy	None	None
8	8 yellow pine 8 Douglas fir	24 hr. Feb. 20-21	38	21	33	95	62	78	February 20, cloudy. February 21, partly cloudy with some sunlight	None	None
10	9 yellow pine 3 Douglas fir	168 hr. Feb. 24-Mar. 3	46	29	36	97	52	81	February 27, partly cloudy. March 3, clear. Remainder of days, cloudy	5%. Injury confined to four yellow pine, on one of which it was severe	None
24	4 yellow pine 12 Douglas fir	24 hr. May 13-14	78	66	70	45	8	34	May 13, clear, bright. May 14, partly cloudy, dull	None	None

TABLE III—Continued

Plot No.	Number of trees	Duration	Temperature °F.			Humidity, %			Weather	Result of treatment, 1931, estimated injury to foliage	Condition of plot, 1934, residual effect
			Max.	Min.	Av.	Max.	Min.	Av.			
25	2 Douglas fir	110 hr. June 1-6	85	42	65	66	8	29	June 1, 3, 4, and 5, clear, bright. June 2 and 6, dull, smoke from forest fires	Trace. Injury confined to two small branches of one tree	None
26	1 yellow pine 5 Douglas fir	144 hr. June 8-14	94	50	68	94	9	59	June 8 and 12, clear, bright. June 9, 10, 11, 13 and 14, cloudy	None	None
36	2 yellow pine 1 Douglas fir	220 hr. July 16-25	90	52	73	91	8	42	Clear, bright sunshine each day	None	None
43	3 yellow pine	198 hr. Sept. 16-24	72	36	55	94	30	57	September 16-20, cloudy, September 21-24, clear, bright	None	None
<i>At 1.25 p.m.</i>											
33	1 yellow pine 7 Douglas fir	120 hr. July 10-15	76	46	61	94	34	65	July 10-11, intermittent sunlight July 12-14, cloudy. July 15, clear, bright	5%. Four Douglas fir very slightly injured. Trace of injury on one-year-old leaves of yellow pine	None

TABLE IV
EFFECT OF SULPHUR DIOXIDE CONCENTRATIONS BELOW 1.00 P.P.M

Plot No.	Number of trees	Duration	Temperature °F.			Humidity, %			Weather	Result of treatment, 1931, estimated injury to foliage	Condition of plot, 1934, residual effect
			Max.	Min.	Av.	Max.	Min.	Av.			
At 0.25 p.p.m.											
18	8 yellow pine 4 Douglas fir	450 hr. Apr. 8-27	96	31	55	94	12	60	April 9, 11, 16, 19-24 and 27; clear, bright. April 10, 12, 15, 17, 18, 25 and 26, dull. April 13, 14, and 25, cloudy April 28-May 1, clear, bright. May 2 and 4, dull. May 3 and 5 clear, bright. May 6, cloudy	None	None
21	8 Douglas fir	450 hr. Apr. 17-May 6	97	31	59	94	14	62		None	None
At 0.50 p.p.m.											
11	25 yellow pine 2 Douglas fir	336 hr. Mar. 3-17	53	26	38	98	32	68	March 3 and 17, clear. March 5, 6, 7, 12, clear, bright. March 4 and 11, cloudy. March 8-10, clear in morning, dull or cloudy in afternoon. March 13-16, partly cloudy	Trace. A few one-year-old leaves on one yellow pine	None
20	4 yellow pine 4 Douglas fir	52 hr. daylight only, Apr. 10-16	90	48	64	92	12	39	April 10, 12, 15, dull. April 11 and 16, clear, bright. April 13-14, cloudy	None	None
22	13 yellow pine 2 Douglas fir	117 hr. Apr. 27-May 2	89	38	60	93	18	65	April 27-May 1, clear, bright. May 2, dull	None	None
39	4 yellow pine 1 Douglas fir	1008 hr. Aug. 14-Sept. 25	86	36	60	94	12	57	August 14, 19, 21, 22, 24, 27, September 7, 15, clear, bright. September 22-24, clear, bright. August 15-18, 20, 23, 25, 28, partly	None	None

TABLE IV—Continued

Plot No.	Number of trees	Duration	Temperature °F.			Humidity %			Weather	Result of treatment, 1931, estimated injury to foliage	Condition of plot, 1934, residual effect
			Max.	Min.	Av.	Max.	Min.	Av.			
									clear, smoke haze caused by distant forest fires. September 8-12, dull. August 26, August 29-September 6, 13, 14, 16-20, cloudy. September 21, intermittent sunshine		
At 0.70 p.p.m.											
34	3 Douglas fir	120 hr., July 10-15	74	46	61	94	38	65	July 10-11, intermittent sunshine. July 12-14, cloudy. July 15, clear, bright	None	None
At 0.75 p.p.m.											
17	5 yellow pine 3 Douglas fir	70 hr., daylight only, Mar. 24-Apr. 1	48	33	42	70	32	50	March 24, 25, 28, 30, 31 and April 1, cloudy, March 26, 27 and 29, clear, bright	None	None
19	6 yellow pine 1 Douglas fir	147 hr. Mar. 26-Apr. 1	48	28	38	95	32	65	See above	55%. 4 smallest pines severely injured	Medium
23	3 yellow pine 10 Douglas fir	72 hr., May 6-9	60	42	49	72	38	59	May 6-9, cloudy	None	None
29	3 yellow pine 3 Douglas fir	120 hr., June 23-28	79	46	63	93	22	65	June 23, intermittent sunshine, June 24 and 28, clear, bright. June 25-27, cloudy	None	None
40	3 yellow pine 1 Douglas fir	334 hr., Aug. 17-31	86	53	69	94	12	46	August 17, 18, 20, 23, 25, 28, partly clear, smoke haze caused by distant forest fires. August 19, 21, 22, 24, and 27, clear, bright. August 26, and 29-31, cloudy	None	None

clear, smoke haze caused by distant forest fires.

September 8-12, dull.

August 26. August 29-

September 6, 13, 14,

16-20, cloudy.

September 21, inter-

mittent sunshine

July 10-11, inter-

mittent sunshine.

July 12-14, cloudy.

July 15, clear, bright

March 24, 25, 28,
30, 31 and April 1,
cloudy. March 26, 27
and 29, clear, bright

See above

May 6-9, cloudy

June 23, intermittent
sunshine. June 24 and
28, clear, bright.

June 25-27, cloudy

August 17, 18, 20,

23, 25, 28, partly

clear, smoke haze

caused by distant

forest fires. August 19,

21, 22, 24, and 27,

clear, bright. August

26, and 29-31, cloudy

winter the transpiration losses from conifers are only 1/55 to 1/251 as great as those in the autumn. In the winter, transpiration losses from conifers are scarcely greater than those from the defoliated twigs of broad-leaved trees. Furthermore, Zacharowa (13), in his work on the gaseous exchange of conifers in winter, obtained very low values for respiration or assimilation in pine and fir, the smallest amount of carbon dioxide being given off by both species from the end of December to the beginning of February. It was found by him that changes in the chlorophyll content of the needles constitute one of the causes which influence the course of assimilation in winter. Over certain periods in the winter the respiration exceeds the assimilation.

It would appear that the susceptibility to dilute sulphur dioxide gas decreases quite markedly with decreasing concentration of gas, so that the trees may be treated with concentrations of 0.25 p.p.m. for an indefinitely long period of time without injury during the growing season. This statement would apply with even greater force in regard to gas visitations occurring in the autumn and winter. During the autumn, conifers were fumigated without ill effects for as long as 1008 hr. with an average concentration of 0.50 p.p.m.

From this experimental work it is clear that the damage to conifers in the Trail area has not been due to the gas visitations which occurred during any one season, except in a limited area about 12 to 15 miles south of Trail, but rather is the result of the presence of gas over a period of years.

Absorption of Sulphur Dioxide by Fumigated Conifers

Analyses were made of the sulphur content of yellow pine and Douglas fir needles during the course of the fumigation experiments at Summerland in order to study the rate of absorption of sulphur dioxide by the trees under different experimental conditions. The samples were collected for analysis immediately before and after each fumigation and the different year's needles analyzed separately. Three years' growth of needles was collected for yellow pine and four years in the case of Douglas fir. The results are given in Tables V to VIII, the amount of sulphur dioxide absorbed by the needles in each experiment being calculated in parts per million on the dry leaf tissue.

It is evident from these data that the rate of absorption of sulphur dioxide by the leaves is a function of (a) the concentration, (b) the duration of the fumigation, and (c) the extent of plant activity, the last being dependent upon the season of the year, temperature, humidity, etc. If the concentration is sufficiently high and prolonged, conifers may absorb appreciable amounts of sulphur dioxide under mild winter conditions with temperatures in the neighborhood of 20° to 45° F. The sulphur dioxide absorbed is not injurious unless the rate of absorption is quite rapid. A high sulphur content does not necessarily indicate injury in foliage. The rate of absorption rather than the actual amount present in foliage is by far the most important factor in determining injury.

TABLE V
EXTENT OF SULPHUR ABSORPTION BY FUMIGATED CONIFERS

Plot No.	SO ₂ treatment	Species	Before or after experiment	Per cent total sulphur, dry basis			
				1 yr. needles	2 yr. needles	3 yr. needles	4 yr. needles
2	4.00 p.p.m. for 168 hr. (Feb. 4-11)	Douglas fir	Before	0.110	0.133	0.170	0.158
			After	0.153	0.286	0.247	0.220
			*SO ₂ absorbed	860	3060	1540	1240
	Injury to foliage 90%	Yellow pine	Before	0.079	0.115	0.113	—
			After	0.198	0.206	0.160	—
			*SO ₂ absorbed	2380	1820	940	—
		Yellow pine	Before	0.061	0.086	0.093	—
			After	0.275	0.303	0.196	—
			*SO ₂ absorbed	4280	4340	2060	—
5	5.00 p.p.m. for 96 hr. (Feb. 12-16)	Douglas fir	Before	0.010	0.010	0.026	0.017
			After	0.041	0.042	0.047	0.062
			*SO ₂ absorbed	620	640	420	900
	Only a trace of injury to fir. No injury to pine	Yellow pine	Before	0.047	0.050	0.071	—
			After	0.053	0.052	0.086	—
			*SO ₂ absorbed	120	40	300	—
12	5.00 p.p.m. for 120 hr. (Mar. 3-8)	Douglas fir	Before	0.044	0.053	0.077	0.086
			After	0.165	0.163	0.175	0.185
			*SO ₂ absorbed	2420	2200	1960	1980
	Injury to foliage 90%	Yellow pine	Before	0.068	0.084	0.091	—
			After	0.137	0.113	0.146	—
			*SO ₂ absorbed	1380	580	1100	—
		Yellow pine	Before	0.045	0.045	0.054	—
			After	0.111	0.098	0.103	—
			*SO ₂ absorbed	1320	1060	980	—

TABLE V—Continued

Plot No.	SO ₂ treatment	Species	Before or after experiment	Per cent total sulphur, dry basis			
				1 yr. needles	2 yr. needles	3 yr. needles	4 yr. needles
14	5.00 p.p.m. for 45 hr, daytime only (Mar. 12-17)	Douglas fir	Before	0.054	0.062	0.076	0.089
			After	0.158	0.258	0.180	0.204
	Injury to foliage 80%	Yellow pine	*SO ₂ absorbed	2080	3920	2080	2300
			Before	0.084	0.090	0.073	—
			After	0.171	0.210	0.154	—
			*SO ₂ absorbed	1740	2400	1620	—
30	5.00 p.p.m. for 40 hr. (June 29-July 1)	Douglas fir	Before	0.050	0.013	0.073	0.065
			After	0.170	0.119	0.149	0.119
	Injury to foliage 100%	Yellow pine	*SO ₂ absorbed	2400	2120	1520	1080
			Before	0.086	0.081	0.102	0.075
			After	0.107	0.164	0.159	0.158
			*SO ₂ absorbed	420	1660	1140	1660
41	4.70 p.p.m. for 216 hr. (Aug. 31-Sept. 9)	Yellow pine	Before	—	0.081	0.080	0.080
			After	0.105	0.124	0.118	0.126
	Injury to foliage 35%		*SO ₂ absorbed	—	860	760	920

*—SO₂ absorbed in p.p.m. by dry leaf tissue.

Wherever there was a marked increase in sulphur content over a period of a few days, the leaves were invariably injured. On the other hand no injury took place if this absorption occurred during a longer period.

The results of the absorption data in the tables are significant wherever the amount of sulphur dioxide absorption during a fumigation is in excess of 274 p.p.m. for Douglas fir and 166 p.p.m. for yellow pine. Values lower than these may be due to experimental error. In the sulphur dioxide treatments with concentrations between 4.0 and 5.0 p.p.m. (Table V) the absorption of gas by the leaf tissue at a rate greater than about 300 p.p.m. per day proved highly destructive to the trees. The same results were obtained in absorption experiments with gas concentrations of 2.0 p.p.m. (Table VI).

TABLE VI
EXTENT OF SULPHUR ABSORPTION BY FUMIGATED CONIFERS

Plot No.	SO ₂ treatment	Species	Before or after experiment	Per cent total sulphur, dry basis			
				1 yr. needles	2 yr. needles	3 yr. needles	4 yr. needles
7	2.00 p.p.m. for 69 hr. (Feb. 17-20) No injury.	Douglas fir	Before	0.022	0.069	0.070	—
			After	0.065	0.098	0.088	—
			*SO ₂ absorbed	860	580	360	—
9	2.00 p.p.m. for 144 hr. (Feb. 24-Mar. 3) Injury to foliage 90%.	Douglas fir	Before	0.114	0.064	—	—
			After	0.205	0.186	—	—
			*SO ₂ absorbed	1820	2440	—	—
		Yellow pine	Before	0.065	0.066	0.058	—
			After	0.173	0.208	0.188	—
			*SO ₂ absorbed	2160	2840	2600	—
15	2.00 p.p.m. for 43 hr., night only (Mar. 18-23) Injury to foliage 70%.	Douglas fir	Before	0.066	0.080	0.080	0.111
			After	0.104	0.136	0.149	0.148
			*SO ₂ absorbed	760	1120	1380	740
		Yellow pine	Before	0.063	0.064	0.067	—
			After	0.118	0.108	0.120	—
			*SO ₂ absorbed	1100	880	1060	—
16	2.00 p.p.m. for 35 hr., daytime only (Mar. 19-23) Injury to foliage 75%.	Douglas fir	Before	0.047	0.062	0.051	0.066
			After	0.090	0.103	0.106	0.112
			*SO ₂ absorbed	860	820	1100	920
		Yellow pine	Before	0.037	0.043	0.047	—
			After	0.136	0.125	0.127	—
			*SO ₂ absorbed	1980	1640	1600	—

*—SO₂ absorbed in p.p.m. by dry leaf tissue.

Sulphur absorption data for a number of plots treated with concentrations of 1.00 p.p.m. of sulphur dioxide are given in Table VII. The rate of absorption during these treatments was in general much lower than in the case of the experiments in Tables V and VI, consequently the needles were in most instances unaffected by the gas.

TABLE VII
EXTENT OF SULPHUR ABSORPTION BY FUMIGATED CONIFERS

Plot No.	SO ₂ treatment	Species	Before or after experiment	Per cent total sulphur, dry basis			
				1 yr. needles	2 yr. needles	3 yr. needles	4 yr. needles
1	1.00 p.p.m. for 120 hr. (Jan. 27-Feb. 3)	Douglas fir	Before	0.022	0.077	0.114	0.118
			After	0.109	0.154	0.150	0.139
	Slight injury 2%	Douglas fir	*SO ₂ absorbed	1740	1540	720	420
			Before	0.060	0.096	0.085	0.108
			After	0.110	0.094	0.107	0.111
			*SO ₂ absorbed	1000	—	440	60
6	1.00 p.p.m. for 113 hr. (Feb. 14-20) No injury	Douglas fir	Before	0.056	0.090	0.087	0.102
			After	0.079	0.134	0.090	0.096
			*SO ₂ absorbed	460	880	60	—
10	1.00 p.p.m. for 168 hr. (Feb. 24-Mar. 3) No injury to fir.	Douglas fir	Before	0.045	0.049	0.070	0.105
			After	0.077	0.061	0.105	—
			*SO ₂ absorbed	640	240	700	—
25	1.00 p.p.m. for 110 hr. (June 1-6) Only a trace of injury.	Douglas fir	Before	0.073	0.052	0.064	0.068
			After	0.097	0.055	0.080	—
			*SO ₂ absorbed	480	60	320	—
26	1.00 p.p.m. for 144 hr. (June 8-14)	Douglas fir	Before	0.073	0.072	0.075	0.081
			After	0.082	0.082	0.076	—
	No injury	Yellow pine	*SO ₂ absorbed	180	200	—	—
			Before	0.054	0.036	0.056	—
			After	0.065	0.075	0.072	—
			*SO ₂ absorbed	220	780	320	—

*—SO₂ absorbed in p.p.m. by dry leaf tissue.

Long continued treatment with concentrations of 0.25 p.p.m. resulted in a relatively large increase in sulphur content without causing any damage to the leaves (See Plots 18 and 21 in Table VIII). Even at a concentration of 0.50

TABLE VIII
EXTENT OF SULPHUR ABSORPTION BY FUMIGATED CONIFERS

Plot No.	SO ₂ treatment	Species	Before or after experiment	Per cent total sulphur, dry basis			
				1 yr. needles	2 yr. needles	3 yr. needles	4 yr. needles
18	0.25 p.p.m. for 450 hr. (Apr. 8-27)	Douglas fir	Before	0.048	0.047	0.053	0.053
			After	0.123	0.088	0.090	0.090
	No injury	Yellow pine	*SO ₂ absorbed	1500	820	740	740
			Before	0.050	0.020	0.026	
			After	0.087	0.053	0.074	
			*SO ₂ absorbed	740	660	960	
21	0.25 p.p.m. for 450 hr. (April 17-May 6)	Douglas fir (new growth)	Before	0.045	0.062	0.081	0.081
			After	0.075	0.101	0.109	0.121
	No injury		After	0.132			
			*SO ₂ absorbed	1740	780	560	800
11	0.50 p.p.m. for 336 hr. (Mar. 3-17) Only a trace of injury.	Yellow pine	Before	0.064	0.065	0.048	—
			After	0.129	0.102	0.096	—
			*SO ₂ absorbed	1300	740	960	—
20	0.50 p.p.m. for 52 hr. (Apr. 10-16)	Douglas fir	Before	0.030	0.065	0.100	0.125
			After	0.081	0.104	0.124	0.139
	No injury	Yellow pine	*SO ₂ absorbed	1020	780	480	280
			Before	0.085	0.064	0.064	—
			After	0.100	0.104	0.094	—
			*SO ₂ absorbed	300	800	600	—
22	0.50 p.p.m. for 117 hr. (Apr. 27-May 2)	Douglas fir	Before	0.080	0.090	0.074	0.099
			After	0.095	0.097	0.101	0.122
	No injury	Yellow pine	*SO ₂ absorbed	300	140	540	460
			Before	0.072	0.062	0.055	—
			After	0.083	0.075	0.072	—
			*SO ₂ absorbed	220	260	340	—

*—SO₂ absorbed in p.p.m. by dry leaf tissue.

TABLE VIII—Continued

Plot No.	SO ₂ treatment	Species	Before or after experiment	Per cent total sulphur, dry basis			
				1 yr. needles	2 yr. needles	3 yr. needles	4 yr. needles
39	0.50 p.p.m. for 1008 hr. (Aug. 14-Sept. 25)	Yellow pine	Before	0.058	0.067	0.076	0.073
			During	0.131	0.121	0.103	0.114
			After	0.192	0.114	0.113	—
	No injury	Douglas fir	*SO ₂ absorbed	2680	940	740	—
			Before	—	—	—	—
			After	0.170	0.166	0.138	0.092
17	0.75 p.p.m. for 70 hr. (Mar. 24-Apr. 1) during daylight only No injury	Yellow pine	Before	0.051	0.057	0.047	—
			After	0.118	0.122	0.092	—
			*SO ₂ absorbed	1340	1300	900	—
19	0.75 p.p.m. for 147 hr. (Mar. 26-Apr. 1) 55% of foliage injured.	Yellow pine	Before	0.059	0.040	0.037	—
			After	0.105	0.087	0.076	—
			*SO ₂ absorbed	920	940	780	—
23	0.75 p.p.m. for 72 hr. (May 6-9)	Douglas fir	Before	0.054	0.050	0.068	0.079
			After	0.069	0.080	0.075	0.075
	No injury		*SO ₂ absorbed	300	600	400	—

*—SO₂ absorbed in p.p.m. by dry leaf tissue.

p.p.m. there were no ill effects suffered by the leaves because of the low rate of absorption compared with that of shorter fumigations involving highly injurious sulphur dioxide concentrations.

The Effect of Sulphur Dioxide on Height Increment in Yellow Pine and Douglas Fir

The fumigation experiments on yellow pine and Douglas fir growing under natural conditions at Summerland, B.C., were terminated in September, 1931. When the plots were next seen in 1934—about three years later—it was at once evident from the appearance of the foliage that most of the affected trees had recovered from the gas treatment to which they had been subjected. At that

time each plot was carefully examined, notes made on the condition of the trees, and most of the plots were photographed. However an attempt was made to obtain a more precise expression of the residual effect of sulphur dioxide upon the trees by studying the rate of growth since the time of treatment. As most of the trees were too small to permit the use of a Pressler increment borer to study diameter increment it was decided to measure the height growth.

In most conifers the annual height growth can be identified for a number of years past. In the present case it was found that the growth of the various years could usually be identified with certainty back to 1928 and so, in order to obtain an indication of the rate of growth before treatment, as well as after, measurements were made back to that year. All forked trees, all trees in which the annual height growth could not be definitely identified, and all trees which for any other reason were unsatisfactory were not used in this study. Measurements were made in feet and tenths, as is usually done in height increment studies. Beginning with Plot 1 all the plots were examined and measurements taken on 100 yellow pines and 111 Douglas firs. In order to have a control or standard of comparison for the growth of the treated trees, similar numbers of the same tree species which were growing near the plots and which had not been fumigated were also measured. These measurements were made in November 1935, and the growth of the trees over a period of eight years was studied.

In the interpretation of the measurements the procedure was first to obtain the average height growth for each year and to plot a graph from these data. It will be noted in the accompanying figures that the yellow pine control shows an average height growth in 1928 of 0.37 ft. In 1929 this rises to 0.41 ft., then falls off fairly rapidly until 1932, after which it rises a little more rapidly until 1935. In the latter year the trees in this group made an average growth of 0.50 ft. In order to contrast the effect upon growth of severe and slight injury, the fumigated trees were divided into two groups: (1) trees from plots which showed 0 to 10% injury to the foliage, and (2) trees from plots which showed 20 to approximately 100% injury. Separate curves for each of these groups were made.

It is evident from Fig. 1 that previous to the year of treatment the rate of growth of the groups of yellow pine is fairly similar. The severely injured group deviated from the other two in 1930 when it rose from 0.35 ft. in 1929 to 0.39 ft. in 1930. For the same years the control and slightly injured groups dropped from 0.41 and 0.39 to 0.35 and 0.34 ft. respectively. This small difference is probably to be accounted for by the fact that the severely injured group contains but 32 trees, while the control and slightly injured groups contain 112 and 68 trees respectively. For 1931 the three graphs practically coincide, the indication being that there was no immediate injurious effect due to the fumigations. Many of the treatments which produced severe, slight, or no injury were applied before the growing season of 1931, and so might have influenced the growth of that year. However, subsequent to 1931 there is a dispersion of

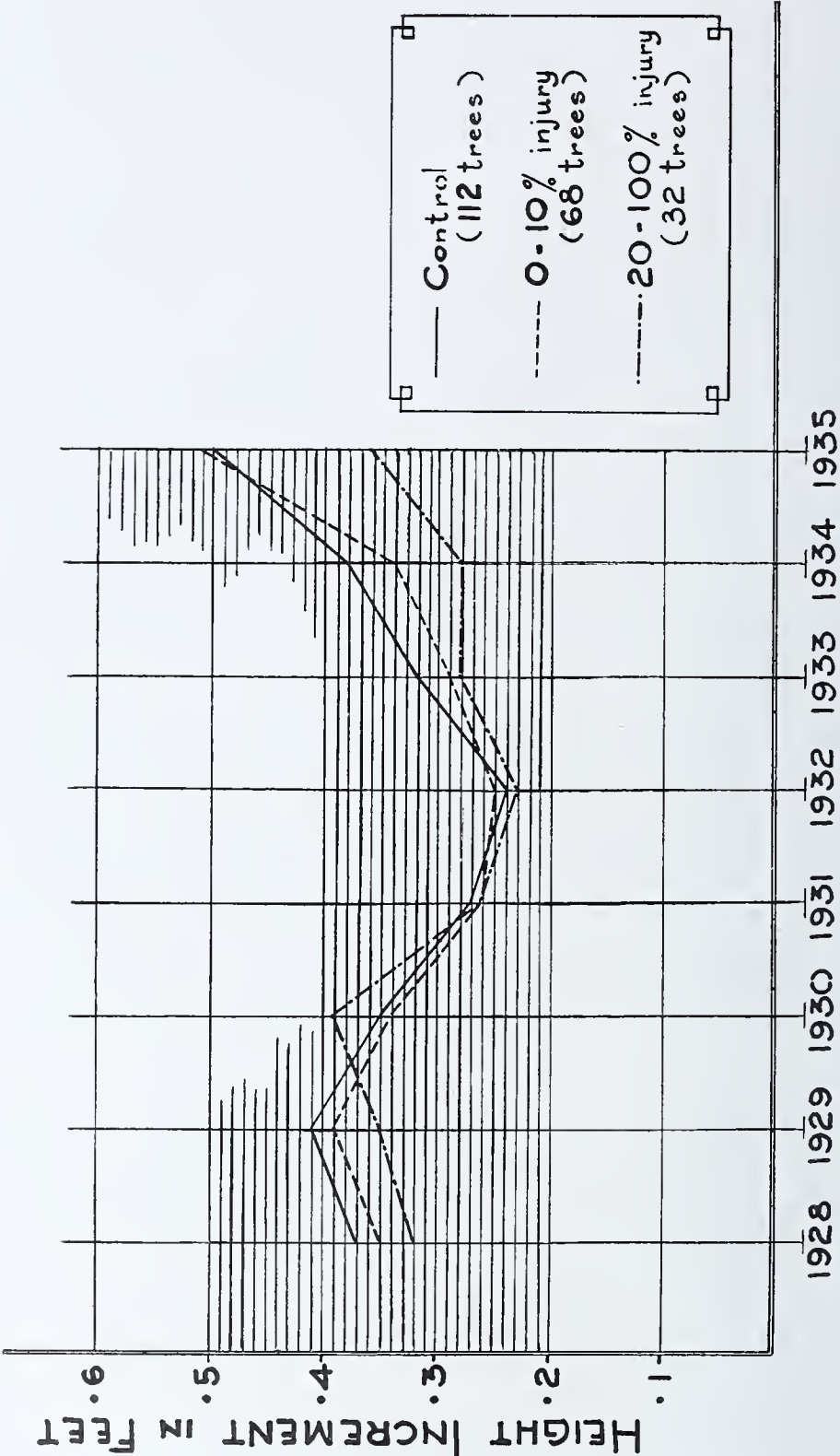


FIG. 1. Height growth of yellow pine treated with sulphur dioxide in 1931.

the three curves, that of the severely injured group falling off to the greatest extent. In this group this retarding effect continues until 1934, after which there is a marked increase in the rate of growth. Although the curve for this group subsequent to 1934 does not lie quite parallel to that of the control group it indicates a substantial recovery. The effects of the treatment with sulphur dioxide on this group are evident, however, for several years.

The effect upon the slightly injured group is not as definite. In 1932 the growth of the control group and that of the slightly injured group are practically identical, but in 1933 and 1934 the growth of the former is slightly better than that of the latter. However, in 1935 the two curves again coincide. In view of the fact that in none of the years under consideration is there much difference in the growth of these two groups and that the curves cross each other several times, the small reduction in the growth of the slightly injured group is not considered to be very significant. If there was an adverse effect upon growth in this group in 1933 and 1934 it was, in any event, very slight.

Similarly, the Douglas fir were divided into three groups—111 trees in the control, 84 in the 0 to 10% injury group, and 27 in the 20 to 100% injury group. Again, as may be seen in Fig. 2, the three curves are very similar previous to 1931. In that year, however, the severely injured group falls off sharply, indicating an immediate effect of the gas treatment upon growth. In the following years up to 1935 while the growth rate improves, the curve still falls considerably below that of the control group. Thus, although the relative rate of growth for the severely injured group is similar to that of the control for 1934 and 1935, the former has not made up the growth lost during 1931, 1932, and 1933. The effect on the slightly injured group is also definite. While the curve for this group and that for the control practically coincide in 1931 they diverge in subsequent years, the control making better growth. In 1934 and 1935 the relative growth rates of the control and slightly injured groups are similar, *i.e.*, the effects of the injury have largely been overcome. As in yellow pine these graphs show that the effects of the treatments have persisted for several years. In Douglas fir the effect of the sulphur dioxide seems to have been more severe than in yellow pine.

In general this study shows that the fumigations of 1931 had a definitely retarding effect upon the severely injured trees and a similar, but much less pronounced, effect upon the slightly injured trees. It was possible to show this retardation in graphical form by the actual measurement of height growth. A study of the graphs shows a greater degree of retardation in Douglas fir. This indicates that this species is more susceptible to injury by sulphur dioxide than is yellow pine, a conclusion which is substantiated by observations made over a period of years in the Trail area. The results presented herewith corroborate the conclusions drawn as a result of the examination of these plots in 1934.

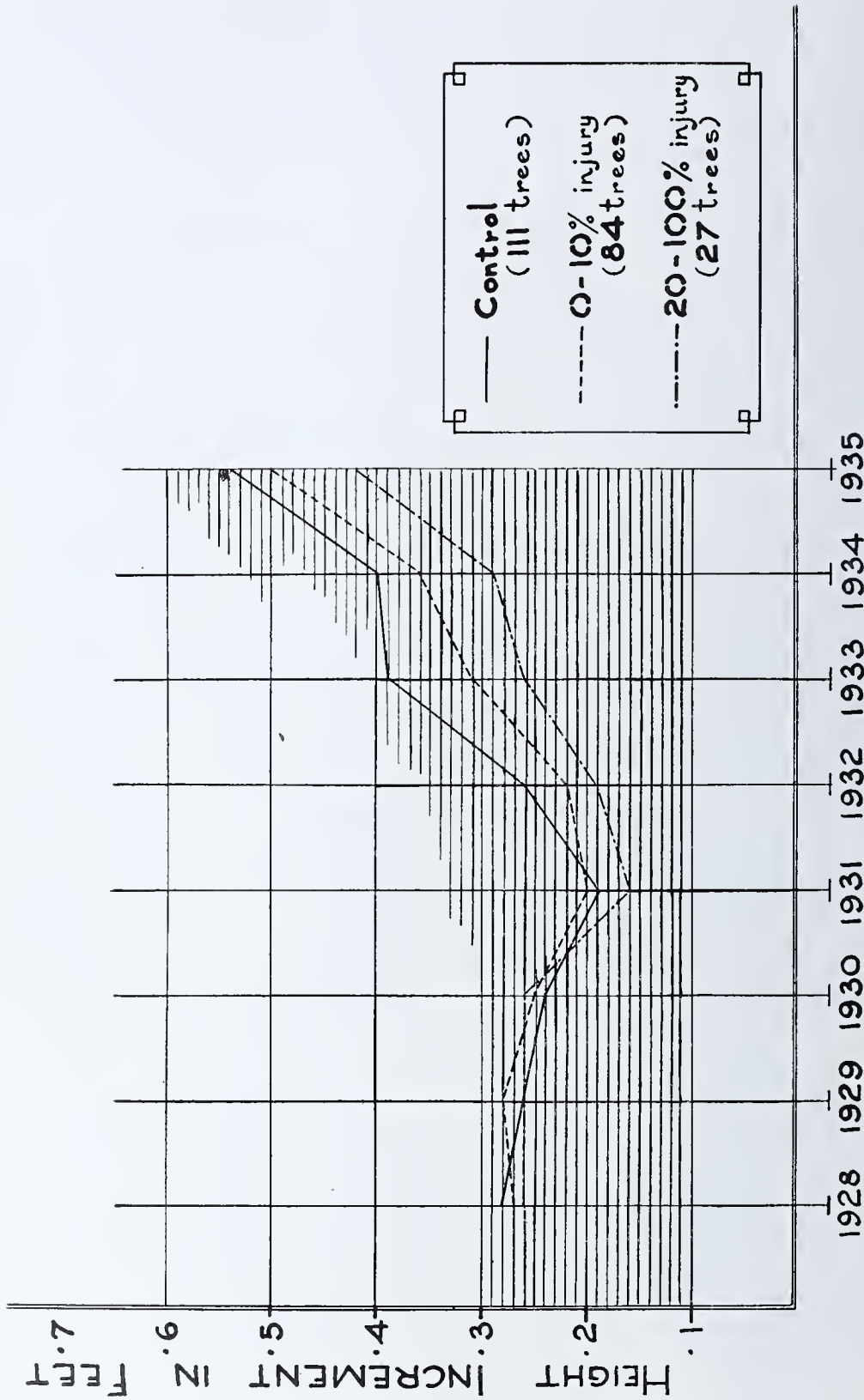
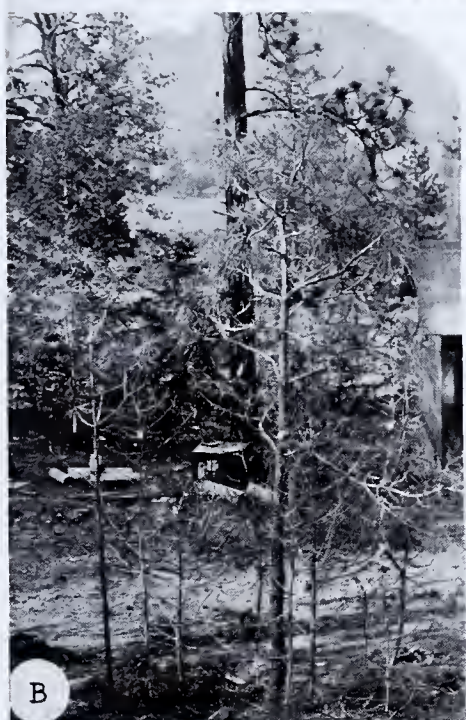


FIG. 2. Height growth of Douglas fir treated with sulphur dioxide in 1931.



A.—Plot 2. Nearly all the leaves on the trees were shed after treatment with sulphur dioxide in February, 1931. Photographed in the summer of 1931. B.—Plot 30. After treatment with 5.00 p.p.m. for 40 hr. two pines were killed and all firs severely injured. Photographed in the summer of 1931. Compare with Plate VI, FIG. 17. C.—Another view of Plot 30 taken at the same time. D.—Plot 5. Compare with Plate III, FIG. 4. Photographed in the summer of 1931.



FIG. 1.—Plot 1. The trees show no residual effect after treatment with sulphur dioxide in 1931. FIG. 2.—Plot 2. The growth of these trees has been slightly retarded. Compare with Plate I, A. FIG. 3.—Plot 3. These trees show no retardation in growth. Plots photographed August 24, 1934.



FIG. 4.—Plot 5. These trees have not been retarded in growth. Compare with Plate I, D. FIG. 5.—Plot 9. All trees show a severe residual effect with considerable retardation. FIG. 6.—Plots 12 and 14. The dividing line between these plots is near the centre of the figure. In Plot 12, one yellow pine was killed by sulphur dioxide, and the remaining trees were considerably retarded in growth, whereas the residual effect on Plot 14 was slight. Plots photographed August 24, 1934.



FIG. 7.—Plot 6. The trees were not retarded in growth. FIG. 8.—Plot 15. These trees show a slight sulphur dioxide effect. FIG. 9.—Plot 18. These trees were treated with 0.25 p.p.m. of sulphur dioxide for 450 hr. without injury in the spring of 1931. There was no residual effect. Note the excellent condition of the foliage. FIG. 10.—Plot 19. These trees show a medium amount of retardation. Plots photographed August 24-25, 1934.

PLATE V



FIGS. 11, 12, 13. These trees show no residual effect after treatment with sulphur dioxide. Plots photographed August 25, 1934.



FIG. 14.—Plot 26. The trees show no residual sulphur dioxide effect. FIG. 15.—Control Plot 27. FIG. 16.—Plot 28. The fir trees show no residual effect although about 40% of the foliage was injured in 1931. FIG. 17.—Plot 30. The two pines are dead and the firs have been retarded considerably. Compare with Plate 1, B and C. Plots 26 and 28 photographed August 25, Plots 27 and 30 photographed October 7, 1934.



FIG. 18.—Plot 31. These trees show a medium residual effect. FIG. 19.—Plot 38. The trees show no noticeable aftereffects. FIG. 20.—Plot 39. This plot was treated with 0.50 p.p.m. for 1,008 hr. in autumn of 1931 without injury. The trees show no residual effect. FIG. 21.—Plot 40. This plot was treated with 0.75 p.p.m. for 334 hr. in late summer of 1931 without injury or noticeable aftereffects. Plots 31 and 38 photographed August 25 and Plots 39 and 40 photographed September 2, 1934.



FIG. 22.—Plot 41. This plot was treated with 4.70 p.p.m. for 216 hr. in the autumn of 1931 and the trees were slightly retarded in growth. FIG. 23.—Plot 42. The trees suffered a slight amount of retardation after treatment with 1.60 p.p.m. for 142 hr. in September, 1931. FIG. 24.—Plot 43. These trees show no aftereffects. The plot was treated with 1.00 p.p.m. for 198 hr. in September, 1931. FIG. 25.—Plot 44. A yellow pine control plot near Plots 11, 17, and 19. Plots 41, 42 and 43 photographed September 2, Plot 44 photographed October 2, 1934.



FIG. 26.—Plot 45. A Douglas fir control plot in the vicinity of Plots 25, 26, 28, and 38. FIG. 27.—Plot 46. A Douglas fir control plot close to Plot 45. FIG. 28.—Plot 47. A yellow pine control plot near Plots 39, 40, 41, 42, and 43. FIG. 29.—Plot 48. A yellow pine control plot near Plot 43. Photographed October 7, 1934.

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CHAPTER X

FUMIGATION EXPERIMENTS ON TRANSPLANTED CONIFERS

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Introduction

In the autumn of 1934 and in the spring of 1935 a series of plots of young conifers was established on the grounds of the Dominion Experimental Station, Summerland, B.C., in order to compare the susceptibility to sulphur dioxide of trees growing in irrigated plots under artificial conditions with the results obtained on conifers in natural habitat in 1931. The trees were planted in six-foot-square plots, generally nine trees to each plot. The following species were transplanted:

		Age, yr.
Douglas fir	— <i>Pseudotsuga taxifolia</i>	3
White fir	— <i>Abies grandis</i>	3
Silver fir	— <i>Abies amabilis</i>	3
Sitka spruce	— <i>Picea Sitchensis</i>	6
Engelmann spruce	— <i>Picea Engelmanni</i>	4
Western white pine	— <i>Pinus monticola</i>	5
Western yellow pine	— <i>Pinus ponderosa</i>	3 to 10
Lodgepole pine	— <i>Pinus contorta</i>	6
Western red cedar	— <i>Thuja plicata</i>	4 to 6
Western hemlock	— <i>Tsuga heterophylla</i>	5
Western larch	— <i>Larix occidentalis</i>	4 to 6

Of the total number of plots, 64 were made up of a mixture of species, while 13 were nearly all larch and 9 contained yellow pine only. The plots were tended carefully during the summer of 1935, being given ample water and cultivation. Most of the trees made fair growth, but even with the best of care it was found difficult to establish certain species under conditions so radically different from those of natural habitat. Silver fir and white fir were maintained with difficulty while only a few of the hemlock survived. The white pine and Sitka spruce thrived only moderately well. Among other factors the low humidity, high temperatures, and intense sunlight of the Okanagan valley, as compared with similar conditions in the forest, were probably of importance in influencing adversely the growth of these species.

Towards the end of September, 1935, it was decided that the trees were sufficiently well established to permit fumigation experiments to be undertaken. Accordingly, between September 26 and December 18, seven of the best mixed plots were treated with sulphur dioxide, the concentrations covering the range from 0.25 p.p.m. in air by volume to about 5.00 p.p.m. and the duration of fumi-

gations varying from 165 to 1,656 hr. At the time of these experiments most of the tree species were about four to five years old, but the lodgepole pine and larch were six years old and some of the yellow pine about ten years old.

A number of fumigation experiments were carried out, principally on larch, during the summer of 1936 from May 21 to June 2 and September 4 to 7. The concentrations used in these experiments were very low, the range being from 0.10 to 0.80 p.p.m. The duration of these experiments varied from 6 to 151 hr.

In order to obtain data in regard to the susceptibility of seedlings and very young trees, a number of experiments were carried out during 1937. In 1934 a quantity of three-year-old yellow pine had been obtained from the United States Forest Service nursery at Missoula, Montana, and set out in plots. By 1937 these young trees were growing rapidly and had attained an average height of about 20 in. with a maximum of 33 in. Also in 1937 a quantity of one- and two-year-old yellow pine and two-year-old Douglas fir was obtained and set out in flats. The seedlings referred to as being one year old germinated in late April or early May, 1937, and therefore at the time of these experiments were only about three months old. Similarly the two-year-old seedlings were actually about fifteen months old. The one-year-old yellow pine was obtained on the grounds of the Dominion Experimental Station, Summerland, B.C., whereas the two-year-old stock was supplied by the Forest Service nursery at Missoula, Montana. The two-year-old Douglas fir was obtained from the provincial Forest Service nursery at New Westminster, B.C. The one- and two-year-old yellow pine averaged about three and eight inches in height, respectively, and the two-year-old Douglas fir about six inches. These seedlings were grown in shallow boxes or flats about one by two feet, and three flats were used in each experiment, one each of one- and two-year-old yellow pine and one of two-year-old Douglas fir. Each flat contained about 80 one-year-old yellow pine, 100 two-year-old yellow pine, or 50 two-year-old Douglas fir.

Experimental

The results of the experiments carried out during the autumn and early winter of 1935 are summarized in Table I. A long experiment with the sulphur dioxide concentration as low as 0.22 p.p.m. indicated no effect on the conifers after 1,656 hours' treatment during the period October 8 to December 18. No marking of any kind was found on the foliage, there was no change in the color of the needles, and no symptoms appeared subsequently.

With higher concentrations of gas it was found that 0.46 p.p.m. produced the first symptoms of injury on spruce after 530 hours' treatment, and on yellow pine, lodgepole pine and white fir, after about 700 hours, during the period September 30 to November 5. Although the experiment was continued for 736 hr., it was rather surprising to find the absence of any symptoms of sulphur dioxide injury on the Douglas fir, and only a trace of injury on a few

TABLE I—Continued

Plot No.	No. of trees	Species	Date	Sulphur dioxide treatment		Temp. °F	Humidity, %	Results (Estimated percentage of leaves injured)
				Duration, hr.	Average concentration, p.p.m.			
76	3	yellow pine	Nov. 23, 11.00 a.m.-	214	0.92	29-47	68-100	Initial symptoms appeared after 96 hours' treatment on Douglas fir and after 144 hr. on yellow pine and lodgepole pine. Degree of injury not estimated.
	2	Douglas fir	Dec. 2, 9.20 a.m.					
	2	lodgepole pine						
	1	larch						
51	3	Douglas fir	Nov. 5, 1.30 p.m.-	264	5.32	19-66	48-100	Douglas fir ----- 100 Sitka spruce ----- 100 Yellow pine ----- 90 Engelmann spruce ----- 90 Lodgepole pine ----- 75 Silver fir ----- 5
	2	yellow pine	Nov. 16, 1.00 p.m.					
	1	Sitka spruce						
	1	Engelmann spruce						
	1	lodgepole pine						
	1	silver fir						
			Sept. 26-Oct. 8	287	Control			No injury

leaves of the cedar. A subsequent examination revealed that the foliage of the Engelmann spruce was completely discolored, whereas that on the yellow pine had been injured to the extent of 20%, with injury of only a minor character evident on the white fir, lodgepole pine, and cedar foliage.

With sulphur dioxide concentrations in the neighborhood of 0.70 p.p.m., an experiment carried out during the period October 9 to 30 indicated a considerable decrease in the time required for the first symptoms of injury to appear. After 48 hours' treatment the characteristic sulphur dioxide markings became evident on several of the Douglas fir trees, while on white pine, cedar, and spruce the first symptoms appeared after 120, 162, and 354 hr., respectively.

Three experiments were carried out with concentrations in the neighborhood of 1.00 p.p.m. (Plots 37, 43 and 76). In the first experiment of this group, carried out from September 26 to October 8, the average concentration of gas was 0.95 p.p.m. for 287 hr. The first symptoms of injury appeared on the tallest Douglas fir sapling within 28 hr. After 72 hours' treatment the remaining two Douglas fir and also the yellow pine began to show the characteristic sulphur dioxide markings. In the case of the other trees, the first symptoms appeared on lodgepole pine, silver fir, and cedar after 144 hours' treatment, and on Engelmann spruce after 168 hr. At the end of the experiment it was found that the spruce, yellow pine, and Douglas fir were severely marked, whereas the lodgepole pine showed markings on about 20% of the needles, and only a trace of injury was evident on the cedar and silver fir.

The second experiment of these three was carried out during the period from November 16 to 23, the temperatures being considerably lower than those prevailing in the previous experiment. The duration of the fumigation was 165 hr. and the gas treatment consisted of 0.45 p.p.m. for 14 hr., 1.25 p.p.m. for 9 hr. and 1.00 p.p.m. for 142 hr. The initial symptoms of injury on Douglas fir and yellow pine in this case appeared after 120 hours' treatment. At the end of the experiment only a trace of injury was present in the needles of white pine, hemlock and cedar, whereas the yellow pine and Douglas fir were severely marked.

The third experiment of this group was carried out during the period from November 23 to December 2 at an average concentration of 0.92 p.p.m. for 214 hr. Initial symptoms of injury appeared after 96 hours' treatment on Douglas fir, and after 144 hr. on yellow pine and lodgepole pine. The temperatures during this experiment were comparatively low, the minimum being 29°F. and the maximum 47°F.

These experiments with concentrations of sulphur dioxide of the same order of magnitude indicate a considerable decrease in susceptibility with decrease in temperature from the end of September to the end of November. This decrease in susceptibility to sulphur dioxide is due in part to the virtual cessation of growth and greatly lowered plant activity with the advent of winter conditions.



FIGS. 1 and 2.—General views of conifer plots with fumigation in progress, Nov. 22, 1935.
FIG. 3.—Two fumigation experiments on conifers. Nov. 22, 1935.

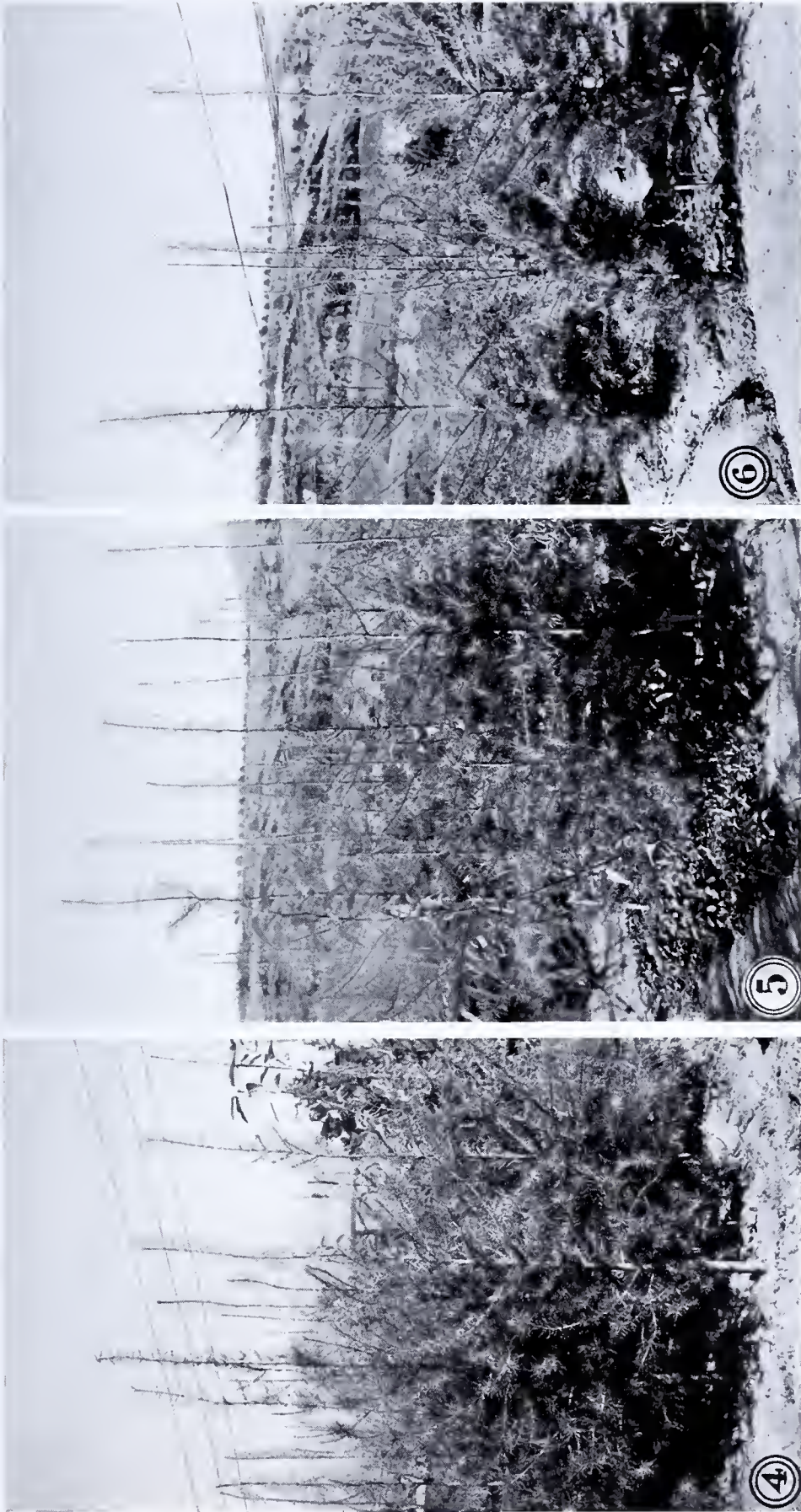


FIG. 4.—Plot 19. FIG. 5.—Plot 23. FIG. 6.—Plot 25. These figures show the condition on September 3, 1936, of the larches which were fumigated earlier in the season.

Also at lower temperatures, sulphur dioxide at a given concentration would be less active chemically.

An experiment carried out with 5.32 p.p.m. for 264 hr. in November serves to indicate the resistance of conifers to sulphur dioxide gas at this season of the year. After 96 hours' treatment, the first symptoms of injury appeared on two of the Douglas fir and after 144 hr. similar symptoms were noted on the yellow pine and lodgepole pine. Only a few needles of the silver fir were found discolored after 216 hours' treatment, whereas the spruce did not show any visible effects at the end of the experiment. About two weeks later, however, on December 2, both the Sitka and Engelmann spruce showed symptoms of injury and began to shed their needles.

The total sulphur content of the conifer needles was determined in the case of four of the experiments carried out during the autumn and early winter of 1935. The results are shown in Table II. In every instance a more or less substantial increase in sulphur content is evident after treatment with sulphur dioxide. It would appear that up to the point of incipient injury the concentration of gas has a greater influence on the rate of sulphur dioxide absorption than the time of exposure. Thus in experiments where the products of the durations and concentrations are similar, a considerably higher rate of increase is shown in needles of the same species in the case of the treatments with the higher concentrations of gas.

Owing to the continuous nature of these fumigations of long duration with relatively high average concentrations, they are equivalent to several years' fumigation at the frequencies and concentrations encountered in the Northport area. The absorption of sulphur by the needles, as indicated in Table II, is considerably higher than would be found in the needles of conifers over a period of a whole year in the region of the Stroh sulphur dioxide recorder. In fact, the sulphur values shown in the experiments on Plots 69, 44, and 76 for yellow pine and Douglas fir are similar to those found in the three- to four-year-old needles of these species in the Columbia River valley in the region of highest sulphur content. In other words, the absorption in these experiments, which were carried out over a period of a few weeks to two and one-half months, is as much as would be found after several years' absorption in the Northport area. It is interesting to note that the sulphur content of Douglas fir needles increased about 100 to 109%, and yellow pine, 165 to 173%, without any resultant injury to the needles. (See experiment on Plot 44.) It would appear, therefore, that when the sulphur dioxide concentration is reduced below a certain minimum value, this gas may be absorbed by the needles and accumulated as sulphate without causing any ill effects.

Experiments on Larch

Six experiments were carried out on plots of larch during the growing season of 1936, five of these being performed during May and June and the last one

TABLE II
SULPHUR CONTENT OF FUMIGATED CONIFER NEEDLES

Plot No.	Species	Date of treatment, 1935	Sulphur dioxide treatment		Total sulphur Per cent on dry leaf tissue			
			Duration, hr.	Av. conc., p.p.m.	Age of needles in years,			
					1	2	3	4
69	Yellow pine Lodgepole pine	Sept. 30- Nov. 5	736	0.46	*0.51 *0.67	0.48 0.43	0.48 0.45	
51	Yellow pine	Nov. 5- Nov. 16	264	5.32	*0.35	0.40	0.36	
44	Douglas fir Yellow pine Lodgepole pine	Oct. 8- Dec. 18	1656	0.22	0.46 0.45 0.32	0.44 0.41 0.35	0.37 0.26 0.32	0.45 0.39
76	Douglas fir Lodgepole pine	Nov. 23- Dec. 2	214	0.92	*0.49 0.35	0.50 0.33	0.46 0.24	
	Yellow pine Lodgepole pine Douglas fir		Control		0.17 0.19 0.22	0.15 0.17 0.22	0.14 0.18 0.23	0.24

* Needles injured by sulphur dioxide.

in September. The results are summarized in Table III. The most significant fact established as a result of the larch fumigations is the extreme sensitivity of this species to sulphur dioxide. In the experiments carried out in May and June only the foliage produced on wood of the current year was injured. The foliage on the older wood was found to be more resistant to gas, and was marked only in September after prolonged fumigations with relatively high concentrations of gas. In this instance it was found that the most recently produced leaves on wood of the current year were the first, and leaves on wood of previous years the last, to show injury.

It was found that slight symptoms of sulphur dioxide injury could be produced on larch foliage at the susceptible time of the year in eight hours during daylight with concentrations as low as 0.30 p.p.m. if the humidity was maintained at an average of 67%. (See Table III, Plot 27.) On the other hand, with the average day-time humidity, about 45%, no symptoms of injury were found after 76.5 hr. continuous exposure to concentrations varying from 0.11 to 0.42 p.p.m., the averages being 0.156 p.p.m. for 70.5 hr. and 0.35 p.p.m. for the remaining 6 hr.

In a long experiment carried out on Plot 23, the trees were fumigated intermittently during the period from May 21 to May 28, the total exposure being 123 hr., at the concentrations indicated in Table III. The first slight symptoms, which appeared on May 25, were confined to the terminal growth of only 2 out of the 12 larch trees in this plot. Coincident with the appearance of these symptoms, wilting of some of the terminal buds was noticed. Additional symptoms developed on the afternoon of May 26. On the following morning it was noted that the injury was still confined to 3 larch trees out of the 12, the affected leaves being found only on the growth of the current year's wood. Only a few twigs contained leaves which were completely injured. Fresh symptoms were observed on May 28, the foliage on one tree in particular being badly injured. The wilting of terminal shoots and leaves was quite pronounced on this tree and the discolorations varied from very pale green to a straw color. Some of the leaves that were injured several days previously were becoming reddish.

By June 16 the injured foliage had taken on a pronounced reddish color and the severely affected leaves were being shed. The weather throughout June was favorable for growth and new leaves appeared on the injured leaders. There was also a considerable development of lateral growth. Fresh buds appeared on the new wood in those trees that contained the highest percentage of injured leaves. This effect was not noticeable on the comparatively uninjured trees although their terminal growth was continued. In the case of the trees from the control plots, the development of buds in June on the new wood was limited to the more vigorous top shoots. There was, along the weaker, lower twigs, no new bud development such as that noted in the injured trees. On September 5 the injured leaves which still remained on the trees were reddish (testaceous

TABLE III
SUMMARY OF SULPHUR DIOXIDE TREATMENT OF CONIFER PLOTS, 1936

Plot No.	No. of trees	Species	Date	Sulphur dioxide treatment		Temp., °F.	Humidity, %	Results
				Duration, hr.	Average conc., p.p.m.			
27	12 2 1	Larch Douglas fir Lodgepole pine	May 29, 7.10 a.m.- 3.10 p.m.	8	0.30	83	67	Very slight injury to leaves on current year's wood on 6 larch. Moderate injury to similar leaves on 2 other larch trees. Remaining trees in plot uninjured.
25	5 2	Larch Douglas fir	May 29, 9.40 a.m.- June 2, 9.00 a.m.	83 12	0.41 0.14	60-94	40-95	Injury in larch confined to leaves in current year's wood. Severe injury on 4 of the 5 larch. One Douglas fir moderately and one slightly injured.
18	14 2	Larch Douglas fir	May 28, 7.00 a.m.- 3.00 p.m.	8	0.43	73	75	Injury in larch confined to leaves on current year's wood. One larch severely injured, 11 moderately and 2 uninjured. One Douglas fir slightly injured and one unaffected.
19	12 2	Larch Douglas fir	May 27, 8.30 a.m.- 2.30 p.m.	6	0.72	78	68	Injury in larch confined to leaves on current year's wood. One larch severely injured, 5 moderately, 4 slightly and 2 unaffected. Both fir slightly injured.
23	12 2	Larch Douglas fir	May 21, 4.00 p.m.- May 28, 5.00 p.m. (intermittent fumigations)	101.0 15.67 3.33 3.0	0.15 0.33 0.47 *0.61	46-100	40-95	First symptoms appeared on larch after treatment for 72 hr. with 0.15 p.p.m., 9.33 hr. with 0.36, and 1 hr. with 0.60 p.p.m. sulphur dioxide. Injury in larch confined to leaves of current year's wood. Leaves of 4 larch severely injured, of 3 larch moderately, of 4 larch slightly. No injury on remaining larch. Two fir slightly injured.

TABLE III—Continued

Plot No.	No. of trees	Species	Date	Sulphur dioxide treatment		Temp., °F.	Humidity, %	Results
				Duration, hr.	Average concentration, p.p.m.			
31	8 2	Larch Douglas fir	Sept. 4, 8.30 a.m.- Sept. 7, 8.30 a.m. (intermittent fumigations)	54	0.70	65-96	37-70	After 5 hr. initial injury occurred on 2 larch. After 6 hr. one larch severely injured, 5 slightly and 2 uninjured. After 9 hr. treatment all larch showed injury to leaves on wood formed during present year. After 11 hr. leaves on wood of previous years showed injury on 6 larch. After 54 hr., 7 larch severely injured and 1 moderately. After 54 hr. a few 1936 leaves on both fir showed injury.

* Maximum concentration 0.80 p.p.m. for 20 min.

to ferruginous) and curled up. In the case of the four larch trees which had been severely marked, some of the shoots were killed.

With higher concentrations of gas the first signs of injury appeared after 4.5 hours' treatment with 0.72 p.p.m., the humidity being maintained at an average of 68%. After six hours' exposure at this concentration definite indications of injury appeared on 7 of the 12 larch trees in Plot 19, the new leaves of the terminal growth being wilted and bleached to almost a straw color. On the following morning, 10 of the 12 larch showed degrees of injury varying from slight to severe. The affected leaves of the larch began to show reddish discolorations about a week to 10 days after treatment, but by June 16, about 20 days after the gas treatment, a substantial recovery had taken place. This recovery consisted of continued growth of terminal leaves and also a considerable development of buds on the new wood, especially on those trees with the heaviest injury.

The last experiment in this series was carried out on Plot 31 in September. The larch varied in height from 3 to 4½ ft., whereas one of the fir was 18 in. and the other 12 in. high. The larch were in excellent condition, showing no sign of autumnal yellowing. The growth had apparently stopped in most of the trees, but two of them had just put out some new leaves. This was in the nature of a secondary growth probably due to the unusually favorable conditions under which the trees were growing. Under natural conditions there would be no new growth of leaves at this time of year.

The purpose of this experiment was to compare the susceptibility of larch at this time of year with that obtaining in May. The trees were treated with an average concentration of 0.72 p.p.m. for six hours, beginning at 8.30 a.m. on September 4. At 1.30 p.m., or five hours after the treatment was begun, injury was noted on the above-mentioned new leaves on two larch trees. Only a very few leaves were marked—about a dozen on one shoot in one tree and a few leaves on each of nine shoots in the other tree. The first signs of injury were manifested by a change of the normal green color to a yellowish green or citrine and a loss of turgor. The wilting effect was present only in very young leaves. An examination of the trees at the conclusion of this six-hour treatment showed that on one tree there was severe injury, on five trees there was slight injury, and on two trees there was no injury in leaves of the current year's wood. The Douglas fir were not affected by this treatment.

The treatment was resumed at 8.30 a.m. on September 5 and continued until 8.30 a.m. September 7, at an average concentration of 0.70 p.p.m. Three hours after the start of this second treatment the two remaining larch also showed traces of injury. Leaves first affected were found, 24 hr. later, to have lost color and to have changed to a straw yellow (honey yellow). On September 6 the leaves formed on wood of previous years began to show traces of injury on six of the larch. The symptoms were similar to those in leaves of the current year, except that there was no wilting.



FIG. 7.—General view of larch plots. FIGS. 8 and 9.—Plot 31, showing severe defoliation of larches as a result of sulphur dioxide treatment. Sept. 7, 1936.



FIG. 10.—Plot 18 showing the wilting effect of sulphur dioxide on the foliage
on the current year's wood of larch, May 29, 1936.

By noon of September 6 the symptoms of injury on larch had become more pronounced. At this time four larch were severely injured, two moderately so, and two only slightly marked. On the morning of September 7 a few leaves of the 1936 growth were found to be marked on both Douglas fir trees. Injury on larch had now progressed to the point where seven trees were severely, and one moderately, injured.

This experiment indicated that newly formed leaves of larch are almost as sensitive in September as in May, but that leaves of the current year which had not been freshly produced are not as susceptible as similar leaves in May. Leaves growing on wood of previous years are more resistant to sulphur dioxide. The results also show that Douglas fir is much more resistant in September than in May.

The sulphur content of larch leaves under different conditions of exposure to sulphur dioxide is shown in Table IV. The leaves treated for relatively short periods show only a small increase in sulphur content, while a very substantial increase is shown in the case of those treated for 123 hr. (Plot 23), and 95 hr. (Plot 25). The data indicate that uninjured leaves may absorb higher amounts of sulphur than injured leaves under the same experimental conditions, so that the sulphur content of foliage in itself is no criterion of injury. This has been found to be equally true of the sulphur content of foliage collected within the Trail-Northport smelter area.

Experiments with Douglas Fir and Yellow Pine Seedlings

During the period between August 6 and 15, 1937, nine experiments with seedling yellow pine and Douglas fir were carried out, seven of these being fumigation experiments and two controls. These seedlings, grown in flats kept well supplied with water, were under close observation for about two months before being fumigated with sulphur dioxide. The results are summarized in Table V.

Slight injury appeared on one-year-old yellow pine seedlings after treatment with 0.49 p.p.m. of sulphur dioxide for nine hours under normal temperature and humidity conditions (Experiment No. 3). In another experiment (No. 5) at higher temperatures but lower humidities, slight signs of injury appeared on a few one-year-old yellow pine and two-year-old Douglas fir seedlings after eight hours' treatment with 0.78 p.p.m. Also after a relatively long treatment of 44.5 hours' duration at 0.29 p.p.m., there were slight markings present on some of the Douglas fir and one-year-old pine seedlings but none on the two-year-old pine. With higher concentrations of about 1.00 p.p.m. for approximately eight hours, somewhat more injurious effects were produced but there was no mortality until the duration of the treatment was prolonged to 15 hr. Under such conditions about 50% of the one-year-old pines and 21% of the two-year-old pines were killed. The Douglas fir seedlings, however, suffered no mortality, only 16% of them being injured.

TABLE IV
SULPHUR CONTENT OF FUMIGATED LARCH LEAVES

Plot No.	Date of treatment, 1936	Sulphur dioxide treatment		Per cent total sulphur (dry basis)		
		Duration, hr.	Av. conc., p.p.m.	1935, uninjured	1936, injured	1936, uninjured
18	May 28, 7.00 a.m.-3.00 p.m.	8	0.43	0.28	0.23	0.22
19	May 27, 8.30 a.m.-2.30 p.m.	6	0.72	0.25	0.19	0.24
23	May 21, 4.00 p.m.-May 28, 5.00 p.m. (intermittent fumigations)	101.0 15.67 3.33 3.0	0.15 0.33 0.47 *0.61	0.37	0.42	0.37
25	May 29, 9.40 a.m.-June 2, 9.00 a.m.	83 12	0.41 0.14	0.43	0.29	0.47
			Control	0.20	—	0.19

* Maximum concentration 0.80 p.p.m. for 20 min.

TABLE V
SUMMARY OF SULPHUR DIOXIDE TREATMENT OF CONIFEROUS SEEDLINGS, 1937

Experiment No.	No. of seedlings	Species	Age, yr.	Date	Sulphur dioxide treatment		Temp., °F.	Humidity, %	Results
					Duration, hr.	Av. conc., p.p.m.			
Seedlings in flats									
1	120	Yellow pine	2	Aug. 6	6	0.50	76-96	45-65	No injury.
	86	Yellow pine	1						
	51	Douglas fir	2						
2	115	Yellow pine	2	Aug. 6	5.25	0.75	70-96	45-60	No injury on yellow pine. 5 Douglas fir slightly injured. (18 leaves affected on the most severely injured)
	69	Yellow pine	1						
	50	Douglas fir	2						
3	135	Yellow pine	2	Aug. 7	9	0.49	70-94	35-70	7 one-year-old yellow pine slightly injured. (9 leaves marked on most severely injured seedling.) No injury on Douglas fir or two-year-old yellow pine
	82	Yellow pine	1						
	51	Douglas fir	2						
4	94	Yellow pine	2	Aug. 7-8	15	1.11	70-98	30-70	Severe injury. 74 two-year-old yellow pine injured, 20 of these killed. 80 one-year-old pine injured, 50 of these killed. 8 Douglas fir injured but none killed
	99	Yellow pine	1						
	49	Douglas fir	2						
5	111	Yellow pine	2	Aug. 9	8	0.78	80-96	35-52	No injury on two-year-old yellow pine. 2 one-year-old yellow pine very slightly injured (2 leaves on each). Slight injury on 5 Douglas fir
	61	Yellow pine	1						
	54	Douglas fir	2						
6	108	Yellow pine	2	Aug. 9	8	1.08	80-98	35-58	No injury on two-year-old yellow pine. Slight injury on 14 one-year-old yellow pine. More pronounced than in Expt. 5. 5 Douglas fir injured moderately
	77	Yellow pine	1						
	58	Douglas fir	2						
7	111	Yellow pine	2	Aug. 9, 10, 11	44.5	0.29	50-98	33-78	No injury on two-year-old yellow pine. 16 one-year-old yellow pine slightly injured. 16 Douglas fir slightly injured
	100	Yellow pine	1						
	52	Douglas fir	2						

TABLE V—Continued

Experiment No.	No. of seedlings	Species	Age, yr.	Date	Sulphur dioxide treatment		Temp., °F.	Humidity, %	Results
					Duration, hr.	Av. conc., p.p.m.			
8	95	Yellow pine	2	Aug. 9	44.5	control cabinet	50-98	33-77	No injury on yellow pine. 15 Douglas fir showed discolorations on tips of some leaves. Cause not known
	75	Yellow pine	1	-11					
	42	Douglas fir	2						
9	110	Yellow pine	2	Aug. 13	48	control cabinet	44-94	24-70	No injury
	80	Yellow pine	1	-15					
	150	Douglas fir	2						
Seedlings in plots									
Plot no.									
36	24	Yellow pine	6	June 21 -22	6.16	0.39	70-85	65-85	3 seedlings injured on tips of leaves. One had 320 leaves injured, one 53, and one 33
16	24	Yellow pine	6	July 30 -31	18.67	0.44	40-85	55-88	No injury
21	24	Yellow pine	6	Aug. 11 -13	48	0.33	60-93	35-70	No injury
35	23	Yellow pine	6	Aug. 14	8	1.08	70-84	46-55	Slight tip injury to a few leaves on 10 pine
15	23 *100	Yellow pine Douglas fir	6 2	Aug. 11 -13	48	control cabinet	60-93	35-70	No injury

* Seedlings contained in two flats.



FIG. 11.—Plot No. 35. Six-year-old yellow pine treated for eight hours at an average concentration of 1.08 p.p.m., humidity 46-55%, Aug. 14. Slight tip injury to 10 out of 24 pine. Aug. 15, 1937.
 FIG. 12.—Plot No. 36. Six-year-old yellow pine treated for 6 hr. and 10 min. at an average concentration of 0.39 p.p.m., humidity 65-85%. June 21-22. Slight tip injury to 3 out of 24 trees. Aug. 7, 1937.
 FIG. 13.—General view of fumigated coniferous seedlings in flats. The yellow pine in the large flats are two years old and in the small flats, one year old. The Douglas fir are two years old. Aug. 10, 1937.
 FIG. 14.—Coniferous seedlings used in Experiment No. 4. Treatment consisted of an average concentration of 1.11 p.p.m., for 15 hr., humidity 30-70%. Severe injury with killing in yellow pine but no mortality in Douglas fir. Aug. 11, 1937.

The first control experiment for these fumigations was of 44½ hr. duration. No effect was observed upon the yellow pine seedlings but almost one-third of the Douglas fir developed reddish brown discolorations upon the distal portion of part of their leaves. Another control test (Experiment No. 9) was immediately carried out under similar environmental conditions for 48 hr. without affecting the seedlings in this case. Also two flats of Douglas fir, of about 100 seedlings which had been placed in the control cabinet containing the six-year-old yellow pine and subjected to the cabinet conditions and air blast for 48 hr., showed no injurious effects. The cause of the discoloration of Douglas fir leaves in the first control experiment could not be definitely ascertained. It may possibly have been a temperature effect.

The experiments indicate that seedlings are much more susceptible to single fumigations than older trees. One-year-old yellow pine was found to be more susceptible than two-year-old seedlings of the same species, whereas the Douglas fir seedlings were not as readily killed by sulphur dioxide as the yellow pine. In the case of one-year-old yellow pine, markings appeared on about 9% of the seedlings after nine hours' treatment with 0.50 p.p.m. of sulphur dioxide.

The first experiment with the six-year-old yellow pine in irrigated plots was carried out in June, and, when compared with similar fumigations carried out later in the summer, shows in a striking manner the seasonal variation in susceptibility. The effect of high concentrations of sulphur dioxide in August is shown in the experiment on Plot No. 35 where slight tip injury resulted from a fumigation with 1.08 p.p.m. for eight hours. A control experiment in which cabinet conditions were maintained for 48 hr. on the plants showed no adverse effects.

Comparative Susceptibility of Conifers under Natural and Artificial Conditions

Some of the results of experiments carried out in 1931, when the work was confined entirely to material growing in natural habitat, are compared in Table VI with the data obtained on conifers transplanted in irrigated plots and fumigated in 1935 and 1936 when the trees had become fully established. A strict comparison is possible only in experiments made at approximately the same time of the year and as far as possible with similar concentrations of sulphur dioxide. Obviously, owing to the effect of seasonal variation in susceptibility to sulphur dioxide, it would be misleading to compare a fumigation carried out during the spring, the period of maximum susceptibility, with one carried out in the fall or winter, the time of year when these trees are most resistant.

The data in Table VI indicate that the transplanted trees are definitely more susceptible to injury by sulphur dioxide than similar species growing under natural conditions. Presumably this is to be accounted for by the more vigorous growth of the latter as well as the higher leaf turgor of the transplanted stock. From the results obtained in the Summerland fumigation experiments

TABLE VI
COMPARATIVE SUSCEPTIBILITY OF CONIFERS IN NATURAL HABITAT AND TRANSPLANTED IN IRRIGATED PLOTS

Conifers in natural habitat				Conifers transplanted in irrigated plots			
Date 1931	Sulphur dioxide treatment		Results	Date 1935	Sulphur dioxide treatment		Results
	Conc., p.p.m.	Duration, hr.			Conc., p.p.m.	Duration, hr.	
Aug. 14- Sept. 25	0.50	1,008	No injury to yellow pine or Douglas fir	Sept. 30- Nov. 5	0.46	736	Symptoms of injury on yellow pine after 700 hr.
Aug. 17-31	0.75	334	No injury to yellow pine or Douglas fir	Oct. 9-30	0.69	483	Symptoms appeared on Douglas fir after 48 hr.
July 16-25	1.00	220	No injury to pine or fir	Sept. 26- Oct. 8	0.95	287	Symptoms appeared on Douglas fir after 28 hr. and yellow pine after 72 hr.
Sept. 16-24	1.00	198	No injury to pine. (No fir in this plot)	Nov. 16-23	1.00	142	Injury to Douglas fir and yellow pine after 120 hours' treatment.
April 27- May 2	0.50	117	No injury to yellow pine or Douglas fir	Nov. 23- Dec. 2	0.92	214	Injury to Douglas fir and yellow pine after 144 hours' treatment
July 10-15	0.70	120	A Douglas fir plot. No injury	1936 May 29- June 1	0.41	83	Douglas fir injured. No pine in this plot
May 6-9 June 23-28	0.75 0.75	72) 120)	No injury to yellow pine or Douglas fir	May 28	0.43	8	Symptoms on fir. (Humidity maintained at 75%)
Aug. 17-31	0.75	334	No injury to yellow pine or Douglas fir	May 27	0.72	6	Slight symptoms on Douglas fir. (Humidity 68%.)
				Sept. 4-7	0.70	54	Slight injury to Douglas fir

the tree species rank as follows in order of susceptibility: larch, Douglas fir, Engelmann spruce, white pine, yellow pine, cedar, lodgepole pine, silver fir, and white fir. This ranking is obtained, not only by observation of the time required for initial injury to appear in the various species, but also by a study of the degree of injury sustained. In certain species, whereas injury does not appear as quickly as in others, the degree or extent of injury may be ultimately much greater. For instance, it was found that, in Engelmann spruce, initial symptoms of injury are slow in appearing but that often severe damage follows. As far as larch, Douglas fir, yellow pine, and lodgepole pine are concerned, these conclusions are substantiated by observations made in the Trail-Northport smelter fumes area.

CHAPTER XI

EFFECT OF ENVIRONMENTAL FACTORS ON THE SUSCEPTIBILITY OF BARLEY AND ALFALFA TO SULPHUR DIOXIDE

BY MORRIS KATZ AND G. A. LEDINGHAM

Introduction

During the course of the investigation undertaken to determine the effect of smelter fumes on vegetation in the area adjacent to the Trail smelter, field observations disclosed certain external factors which were invariably necessary for the appearance of symptoms of injury on vegetation. Among these may be mentioned a relatively high concentration of gas, prolonged exposure because of the persistence of the wind in a given direction, and high relative humidity. Sulphur dioxide visitations which were found to cause damage were generally those occurring in the spring and early summer when vegetation was developing rapidly, and not too far advanced in growth.

It was also observed that gas visitations which occurred during the night were relatively harmless, and, furthermore, during periods of prolonged drought there was a total absence of acute symptoms. It was considered highly desirable, in view of the above observations and the conflicting data in the literature on the susceptibility of the plant, to carry out a series of experiments under carefully controlled conditions during the course of experimental fumigation work at the Dominion Experimental Station, Summerland, B.C., in order to elucidate as clearly as possible the influence of various internal and external factors on susceptibility.

Among the factors which have been investigated are the concentration and rate of absorption of gas, the time of exposure, the relative humidity, light, soil moisture, age of the plant, stomatal behavior and rate of carbon dioxide assimilation. This chapter deals mainly with the external environmental conditions, the effect of sulphur dioxide on stomata and carbon dioxide exchange being discussed separately in other chapters of this book.

Review of the Literature

Much of the early work described in the literature was carried out under static conditions and the exact concentration of sulphur dioxide was consequently not known. There has been considerable difference of opinion as to the minimum concentration of sulphur dioxide which is injurious to plants and the various environmental conditions that render plants susceptible to injury. Some of the factors which influence the toxicity of sulphur dioxide on plants have been discussed by Stoklasa (5) in his work on the effect of smoke on vegetation, and also in the extensive review of the literature on the same subject by Haselhoff, Bredemann and Haselhoff (1). Stoklasa mentions that sulphur

dioxide is not as damaging to plants at night as during daylight, and that the toxic effect of this gas is increased with increase in temperature and light intensity. Haselhoff, Bredemann and Haselhoff state that injury by sulphur dioxide depends on the intensity of the fumigation and to a large extent on the age and actual state of the vital functions of the plant. They observe that in sunny weather after a warm rain, or in the early morning after a heavy dew, injuries are particularly apparent in areas subject to pollution by this gas. Light promotes sulphur dioxide injury, and, unless the concentrations are very high, plants are injured only slightly, or not at all, in darkness.

In the Selby report (3) it is stated that there are three factors which vitally influence the amount of injury that can be produced by sulphur dioxide. These factors are concentration of sulphur dioxide, duration of exposure to the gas, and the quantity of water vapor present in the atmosphere during the time of fumigation. The effect of light, though distinct, is of minor importance. The humidity is of far greater importance than temperature or the influence of sunlight and shade.

Swain (6) states that the relative humidity of the atmosphere is one of the most important factors in controlling the effect of sulphur dioxide on vegetation. There is not much increase in sensitivity from 70 to 100% relative humidity, but the resistance of a plant increases more rapidly when the humidity drops below 70% and becomes very pronounced below 50%. He also mentions that four conditions must be coincident for damage to occur to vegetation in those smelting districts where the concentrations of sulphur dioxide are uniformly low. These are daylight, atmospheric humidity of 60% or over, temperature above 5°C., and a steady prevailing wind in a given direction.

In regard to the concentration-time factors, Thomas and Hill (2, 7) have shown, in the case of their work and O'Gara's, that with increasing concentrations of sulphur dioxide the time required for injury to alfalfa decreases quite markedly in the range between 0.30 and 2.00 p.p.m. According to O'Gara (4), the active part of the gas necessary to produce a certain effect on the plant cell multiplied by the time through which it acts is a constant. O'Gara considers relative humidity of the atmosphere to be a very important factor in connection with the effect of sulphur dioxide on plants.

Zimmerman and Crocker (8) found that shading the plants under fumigation was not effective in preventing injury from sulphur dioxide, but if the plants were kept in the dark for two hours prior to fumigating in a dark cabinet they were much more resistant than comparable plants treated while in light. However, darkness was not as effective in bringing about resistance as the wilted condition of the plants. The degree of turgidity of the leaves appeared to be a very important factor, and whereas turgid tomato plants were severely injured when fumigated with 4.2 p.p.m. for five hours there was no injury on wilted plants given the same treatment. They found that a difference of 20%

in relative humidity had no appreciable influence on susceptibility. It was thus concluded that the internal condition of the plant was more important than the external humidity in inducing injury from sulphur dioxide.

Experimental Results

A considerable number of experiments were carried out on Hannchen barley and Grimm alfalfa during the growing seasons of 1931 and 1935-1937, in order to study the more important factors that affect the susceptibility of these species, which are known to rank among the most sensitive of the cultivated plants, to sulphur dioxide. The arrangement and dimensions of the plots and the type of equipment used have already been described in Chapter VIII. The average values of concentration of sulphur dioxide, temperature, relative humidity and light intensity, given in the various tables, were in most cases computed from continuous records for each experiment. With regard to the absorption of sulphur dioxide by the leaves, the extent of absorption from the gas stream was calculated from the intake and exit concentrations of gas in the experimental cabinets, due allowance being made for the soil and cabinet absorption under the various experimental conditions. At least two, and in many cases three or more replicate experiments were made to establish a result under a given set of conditions.

CONCENTRATION-DURATION FACTORS

Barley

In regard to the susceptibility of barley to increasing concentrations of sulphur dioxide gas and the time of exposure for incipient injury on the leaves, the results obtained from over 70 experiments carried out in 1931 have been incorporated in Table I. In the range of concentrations between 0.30 and 5.00 p.p.m. in air by volume the results clearly indicate that with increasing concentration of gas there is a marked reduction in the time of exposure necessary for the first symptoms of injury to appear on the leaves. Thus at a relative humidity of 60 to 70% young barley plants (age from date of seeding, about 18 to 35 days) showed symptoms of chlorotic or chronic injury after 35.1 hr. of fumigation at 0.30 p.p.m. With concentrations of 0.50 to 0.60 p.p.m. first symptoms of injury appeared in 8 hr., with 0.90 p.p.m. in 4 hr., and with 1.20 p.p.m. in 2.5 hr. With higher humidity (90 to 100%) first symptoms appeared with 0.30 p.p.m. in 17.3 hr., with 0.50 to 0.60 p.p.m. in 4 hr., and with 1.20 p.p.m. in 1.75 hr.

The data in Table I represent in general the results obtained with continuous treatment at the indicated concentrations. In a few instances in the case of low concentration experiments the plants were treated with gas during daylight for several days before the first symptoms appeared, but such intermittent treatments followed one another so closely that the effect was almost similar to that of a continuous fumigation. With average concentrations below 0.30 p.p.m. even a highly susceptible plant, such as barley, will withstand prolonged ex-

TABLE I

RELATION BETWEEN CONCENTRATION OF SULPHUR DIOXIDE AND DURATION TO FIRST SYMPTOMS OF INJURY ON BARLEY

Average concentration of sulphur dioxide, p.p.m.	Humidity, 25-35 %		Humidity, 40-50 %		Humidity, 60-70 %		Humidity, 90-100 %
	Young barley hr.	Barley in flower hr.	Young barley hr.	Barley in flower hr.	Young barley hr.	Barley in flower hr.	Young barley hr.
0.30	72.6*	—	—	—	35.1	—	17.3
0.35—0.40	—	—	—	—	25.1	—	10.5
0.50—0.60	30.75	—	13.6	21.75	8.0	15.75	4.0
0.75	—	—	9.0	—	6.0	—	3.5
0.90	—	19.0	8.0	—	4.6	—	2.8
1.00	—	—	5.8	—	3.3	9.0	2.4
1.20	12.75	—	—	12.6	2.5	—	1.75
1.50	6.5	7.25	3.3	—	—	6.9	—
2.00	—	—	3.0	7.6	—	4.25	—
3.00	—	—	—	4.7	—	—	—
5.00	2.0	—	—	—	—	—	—

* Plants were not injured.

posure without toxic effects. Thus Plot G-6 was treated with gas during a period of 20 days from the time the plants were in the fifth leaf stage and about 15 in. in height, with an average of 3.5 tillers per plant, until the barley had reached the flower stage. The total duration of the treatment was 209 hr. and 50 min., and the average concentration was 0.258 p.p.m. The maximum concentration during each fumigation in the pre-flowering period was maintained below 0.50 p.p.m., the highest maximum being 0.49 p.p.m. At the flower stage the sulphur dioxide concentration was allowed to reach a maximum of 0.79 p.p.m., with an average of 0.75 p.p.m. for one hour. The fumigated plants were kept under very close observation, but at no time did there appear to be any symptoms of sulphur dioxide injury, and the growth and development of the barley were normal in every respect.

In another long experiment, consisting of a series of intermittent sulphur dioxide treatments on a large 12 by 12 ft. plot of barley, the first symptoms of injury appeared on the leaves after 14 treatments totalling 124 hr. in duration, the average concentration being 0.29 p.p.m., the maximum, 1.05 p.p.m., and the minimum, 0.04 p.p.m. In this experiment the concentrations were de-

liberately varied in order to approximate as closely as possible the range of concentrations found in gas visitations in the Trail smoke area during May and June of 1931, at a point 15 miles south of Trail, B.C. Treatments were applied over a period of 22 days, beginning at the time the barley was only about 3 in. in height with one or two leaves on each plant. When the first symptoms of injury appeared the plants were 20 in. in height, in the seventh leaf stage, and had an average of six tillers per plant. The symptoms consisted of markings on the tips of the fifth, sixth, and seventh leaves of about 25% of the plants, involving less than 1% of the total leaf area of the plot. Maximum concentrations in excess of 0.40 p.p.m. were present in the cabinet during each one of the 14 treatments, and in excess of 0.60 p.p.m. in 11 of these treatments. The relative humidity was quite high, the maximum being 95% and the minimum 54%, during the final long treatment of 47.75 hr. which preceded the appearance of these initial symptoms of injury. In the case of these recurrent sulphur dioxide treatments on the same plants it was clear that the initial injury was due to the presence of peak concentrations considerably higher than the average.

Alfalfa

The relation between increasing concentration of sulphur dioxide and time of exposure for incipient injury on alfalfa in a stand established two to three years is shown in Tables II, III, and IV. Four long experiments of over 500 hours' duration were carried out with concentrations below 0.20 p.p.m., in three of these—0.10 p.p.m. for 504 hr., 0.11 p.p.m. for 602 hr., and 0.16 p.p.m. for 562.5 hr.—no markings were found on the leaves. In another experiment with an average concentration of 0.14 p.p.m. for 525 hr., markings were found at the end of the experiment on only 3% of the leaves. In three experiments carried out with average concentrations of 0.17 to 0.18 p.p.m., but with the average relative humidity higher than in the above experiments, markings were produced in 95 to 115 hr. With concentrations of 0.20 p.p.m. and an average relative humidity of 58% there was no injury after 87.5 hours' exposure; whereas under similar conditions of humidity the plants showed slight markings after 66.5 hours' treatment with 0.30 p.p.m.; and at slightly higher humidity markings were obtained in 43 hr. with concentrations of 0.38 p.p.m. Slight markings were obtained in 17 hours' exposure to an average concentration of 0.41 p.p.m. at an average humidity of 83%.

The data in Table III indicate the effect of increasing concentrations in the range of 0.50 to 3.00 p.p.m. under various external conditions. The results shown in this table represent the mean of a considerable number of experiments at each indicated concentration. Susceptible plants, such as barley and alfalfa, are unable to tolerate concentrations in excess of 1.00 p.p.m. for longer than a few hours without toxic effect. With concentrations of 1.50 p.p.m., or higher, alfalfa plants are readily injured in about one hour or less in full sunlight, with the humidity higher than 50%.

TABLE II

RELATION BETWEEN CONCENTRATION OF SULPHUR DIOXIDE AND DURATION FOR FIRST SYMPTOMS OF VISIBLE MARKINGS ON GROWING ALFALFA
(Continuous fumigations)

Sulphur dioxide concentration, average, p.p.m.	Relative humidity		Average relative humidity, %	Duration, hr.	Remarks
	Day min., %	Night max., %			
Average humidity below 70%					
0.10	46	100	—	504.0	No injury
0.11	37	98	—	602.0	No injury
0.14	30	95	—	525.0	3% marked leaves
0.16*	36	98	—	562.5	No injury
0.20	32	87	58	87.5	No injury
0.20	32	76	57	87.5	No injury
0.20-0.30	38	90	65	70.5	Slight markings
0.28	30	82	57	87.25	No injury
0.30	34	80	54	66.5	Slight markings
0.35	45	74	60	43.5	Slight markings
0.38	46	75	60	43.0	Slight markings

Average humidity above 70%

0.17	52	100	79	95.0	11% marked leaves
0.17	52	100	79	112.5	15% marked leaves
0.18	48	77	71	115.0	Slight markings
0.24	71	95	84	46.0	Slight markings
0.40	64	78	67	49.0	Slight markings
0.41	80	92	83	17.0	Slight markings

*—Intermittent treatment.

TABLE III

DURATION IN HOURS FOR FIRST SYMPTOMS OF INJURY ON ALFALFA AT THE MOST SUSCEPTIBLE STAGE

Sulphur dioxide concentration, average, p.p.m.	Daylight or full sunlight			Darkness or partial sunlight			
	40-60% Relative humidity	60-80% Relative humidity	Above 80% relative humidity	Below 80% relative humidity		Above 80% relative humidity	
	Hr.	Hr.	Hr.	Hr.	Humidity, %	Hr.	Humidity, %
0.50	—	10.0	5.5	42.0	30-69	—	—
0.50	—	—	—	34.0	54-90	—	—
0.60	—	8.0	—	19.5	56-79	—	—
0.75	11.0	5.0	2.25	17.6	52-82	—	—
0.75	6.5	4.0	—	—	—	—	—
1.00	4.0	2.0	—	21.0	34-71	—	—
1.00	4.0	2.0	—	17.0	58-78	—	—
1.00	4.0	2.5	—	14.0	60-83	—	—
1.25	2.5	2.0	2.0	16.5	55-73	6.5	80-90
1.50	—	1.25	—	20.0	36-69	7.5	80
1.50	—	—	—	15.0	57-80	—	—
1.75	1.25	1.0	0.75	—	—	—	—
2.00	1.17	1.0	—	19.0	49-79	—	—
3.00	0.75	0.66	—	—	—	—	—

TABLE IV
COMPARATIVE SUSCEPTIBILITY IN DAYLIGHT OF ALFALFA AT COTYLEDON
AND LATER GROWTH STAGES

Age from date of planting or last cutting, days	Sulphur dioxide treatment		Humidity, %	Percentage of cotyledons or leaves injured	Remarks
	Concentration, p.p.m.	Duration, hr.			

Seedling alfalfa—cotyledon stage					
15-17	0.52	67.5	30-75	None ²	Two 6-hr. fumigations, daylight
11	0.62	12.0	55	None	
13	1.05	4.0	45	None	
13	2.03 ¹	2.6	50	None	
14	2.04	6.0	49	None	

Seedling alfalfa—plants less than 6 in. in height					
27	0.66	6.0	51	None	Two intermittent 6-hr. fumigations
30	0.65	12.0	50	8	
28	0.71	6.0	40	1)	Two intermittent treatments during interval of 3 days
31	0.62	6.0	60	25)	
32	0.90	4.0	68	40	First injury in 1.5 hr.

Seedling alfalfa—plants 6 to 20 in. in height					
39	0.35	21.0	22-38	Very slight	Three intermittent daylight treatments
38	0.50	8.0	38-52	15	Two intermittent treatments in daylight
37	0.50	10.0	42-50	21	
32	0.50	23.0	30-71	16	First symptoms in 9 hr.
33	0.75	7.75	28-35	25	First symptoms in 4 hr.
34	0.75	4.0	31-41	10	First symptoms in 4 hr.
46	0.75	4.0	65-90	10	First symptoms in 2 hr.
35	1.50	2.5	42	30	First symptoms in 1.5 hr.

TABLE IV—Continued

Age from date of planting or last cutting, days	Sulphur dioxide treatment		Humidity, %	Percentage of cotyledons or leaves injured	Remarks
	Concentration, p.p.m.	Duration, hr.			
<i>Two- to three-year-old alfalfa—during growing period</i>					
11	0.46	48.0	44-80	52	
24	0.54	44.0	52-80	25	
20	0.59	8.0	59	5	Two 4-hr. treatments
25	0.65	8.0	65	2	Two intermittent 4-hr. fumigations
20	0.76	4.0	62	slight	
22	0.96	4.0	58	3	
20	1.01	4.0	57	1	
25	1.32	4.0	48	25	First symptoms injury in 2½ hr.
30	1.91	5.0	50-60	53	First symptoms injury in 1 hr.
12	2.05	6.0	40	25	First symptoms injury in 1.16 hr.

¹ Concentration accidentally increased to 6.4 p.p.m. for 18 min. in one experiment.

² Very slight marking on new leaves.

INFLUENCE OF RELATIVE HUMIDITY ON SUSCEPTIBILITY

The relative humidity of the atmosphere is probably one of the most important external factors in connection with the susceptibility of plants to sulphur dioxide. When light and soil moisture are not limiting factors a high relative humidity favors the opening of the stomata; this results in a high rate of absorption of sulphur dioxide. Furthermore, with the soil moisture favorable for growth, high relative humidity brings about a higher degree of leaf turgor. Under such conditions plants may be quite susceptible even if the light intensity is relatively low. When the relative humidity is in the neighborhood of 100% the time required for injury decreases markedly at a given concentration. On many occasions when sulphur dioxide markings were found on plants in the Trail smelter fumes area the gas visitations coincided with periods of cloudy or rainy weather, when the relative humidity was higher than normal. The effect of relative humidity is probably related to its influence on the movement of the stomata and increase in leaf turgor, which, in turn, affects the rate of absorption of sulphur dioxide.

Barley

The data given in Table I show the effect of increasing humidity on the susceptibility of barley to sulphur dioxide. Young barley plants were treated with 0.30 p.p.m. of sulphur dioxide for 72.6 hr. continuously without injury when the humidity was maintained between 25 and 35%. On the other hand, when the humidity was increased to 90 to 100% the plants were injured in 17.3 hr. With concentrations of 0.60 p.p.m. young barley showed the first symptoms of sulphur dioxide markings after about 30 hours' exposure at 25 to 35% relative humidity, after 8 hr. at 70% and after 4 hr. at 95% relative humidity. Similarly when the concentration was increased to 1.20 p.p.m. the first symptoms appeared in 12.75 hr. with the humidity 25 to 35%, whereas at 70% humidity the time of exposure was reduced to 2.5 hr.

Alfalfa

The influence of the relative humidity of the atmosphere on the susceptibility of alfalfa is shown in Tables II and III. Table II deals mainly with relatively long fumigations and low concentrations of sulphur dioxide, and the data do not show the influence of humidity on susceptibility in as clear a manner as in the case of Table III, where the sulphur dioxide concentrations are considerably higher and there is also a wider range in humidity for purposes of comparison.

In a long experiment with an average concentration of 0.16 p.p.m. for 562.5 hr., the plants being fumigated intermittently throughout a period of 37 days, which represents almost the entire growth period of a crop of alfalfa at Summerland, B.C., no markings were produced on the leaves. The average humidity during this period of fumigation was below 70%, the minimum being 36%, and the maximum, 98%. Three experiments carried out with concentrations of 0.17 to 0.18 p.p.m., but with the average humidity 71 to 79%, resulted in injury to alfalfa after 95 to 115 hours' exposure. With a concentration of 0.28 p.p.m. and average relative humidity of 57% no markings were apparent after 87 hours' treatment; whereas at an average humidity of 84% markings were produced in 46 hr. with a concentration of 0.24 p.p.m. With average concentrations of about 0.40 p.p.m. slight markings were produced in 49 hr. when the average humidity was 67% and in 17 hr. when the average humidity was 83%.

The results in Table III show the effect of humidity in a similar way. At a concentration of 1.00 p.p.m. alfalfa plants were injured in two hours with the humidity 60 to 80%, and in four hours when the humidity was about 20% lower. On the other hand, when the concentration was increased beyond 1.00 p.p.m. the relative humidity became a minor factor and rapid injury took place in the range of 40 to 80% or higher in daylight under comparable growth conditions.

THE INFLUENCE OF AGE OF PLANT ON SUSCEPTIBILITY

Barley

Young barley is much more susceptible to injury by sulphur dioxide than barley in the flower stage. During the period when the young plants are developing leaf tissue and tillering out rapidly the susceptibility to sulphur dioxide is high. The youngest middle-aged leaves are more susceptible than the older leaves, so that plants in the 5th and 6th leaf stage when fumigated invariably show the first symptoms on the 4th, 5th and 6th leaves, but not on the 1st and 2nd leaves, unless the concentrations are relatively high. For equal concentrations of sulphur dioxide the rate of absorption is far less for old leaves than for young leaves, as shown by analyses of the sulphur dioxide content before and after fumigation. The increased resistance with advancing age of the leaf is probably due to the lessening of photosynthetic activity. The plant as a whole shows a considerable increase in resistance to sulphur dioxide gas when in the flower and head stage of growth compared with that of plants about 10 to 30 days old. At the site of the Stroh automatic sulphur dioxide recorder in the Trail smelter area, barley plants on experimental plots showed symptoms of sulphur dioxide injury in 1930 and 1931 during this early stage of growth, and never after the plants appeared in the shot blade and flower stage.

In connection with the fumigation experiments at Summerland, B.C., the data obtained on the relative susceptibility of young barley as compared with that in flower are shown in Table I. Growing barley is, roughly, twice as susceptible as barley at the flower stage to sulphur dioxide concentrations of the order of 0.60 to 2.00 p.p.m. Barley exhibits only slight differences in susceptibility up to the age of about 35 days, although in general the fully functional, middle-aged leaves are marked first. After about 40 days' growth, when the plant enters the shot blade stage, the resistance to sulphur dioxide increases noticeably until the age of 52 to 55 days, when the change in susceptibility is most marked.

Alfalfa

Hill and Thomas (2) state that almost invariably the fully grown, highly functional leaves of alfalfa are injured first and, in a given fumigation, are more severely injured than the remaining leaves on the plant. The authors have also found this to be true. Except under conditions resulting in very severe injury, the very young, rapidly expanding, leaves of alfalfa are seldom affected by sulphur dioxide. The old, lower leaves are also comparatively resistant. Zimmerman and Crocker (8) found that the middle-aged leaves were the most sensitive, followed by the old, and then the young, growing leaves which were the most resistant. This effect has been noted consistently by the present authors throughout the course of the work on alfalfa. Furthermore, alfalfa about a week old or less from the date of cutting of the previous crop is quite resistant to sulphur dioxide in comparison with growing alfalfa during the

interval from about one week after cutting until the flower stage. Alfalfa shoots and leaves which develop from the crown during the week after cutting draw a considerable portion of their carbohydrate requirements from the roots of the plant. The photosynthesis is maintained at a low level during this period. Over the greater part of the growth period, however, and up to the flower stage, alfalfa is about equally susceptible. In the advanced flower stage the plant becomes more resistant to sulphur dioxide.

The stems and buds of plants are extremely resistant to sulphur dioxide. The same is true of the floral portions of plants. In the case of alfalfa the writers have seldom, if ever, encountered an alfalfa stem with sulphur dioxide marks on it, and this result is confirmed by the work of Hill and Thomas. The floral portions of alfalfa are affected only under conditions of drastic treatment with very high concentrations of sulphur dioxide. The leaf buds are uninjured, even under conditions when 50% or more of the alfalfa leaves in a plot may be destroyed by sulphur dioxide. This is probably one of the reasons for the rapid recovery which is manifest following a severe treatment. The rapidly expanding young leaves and leaves formed from the buds soon replace most, if not all, the damaged leaves.

The results of a number of experiments on alfalfa at the cotyledon and later stages of growth are given in Table IV. Alfalfa in the cotyledon stage, 11 to 17 days only from the date of seeding, is extremely resistant to sulphur dioxide. The cotyledons showed no trace of injury with treatments which would have caused severe damage to the leaves. It is notable that treatments with 0.52 p.p.m. for 67.5 hr. and 2.04 for 6 hr. were without effect. The lack of susceptibility of alfalfa cotyledons to sulphur dioxide is probably due to the fact that the plants at this time are living largely on the reserves of carbohydrates in the seed. The rate of photosynthesis is low and there is very little absorption of sulphur dioxide.

As soon as the alfalfa passes out of the cotyledon stage and the leaflets begin to appear, the plant becomes susceptible to sulphur dioxide gas. This is clearly shown by the data on seedlings less than 6 in. in height and 27 to 32 days old from the date of seeding. In marked contrast to the experiments on cotyledons, concentrations of 0.65 p.p.m. for 12 hr. and 0.90 for 4 hr. caused injury to the leaves.

Seedlings, 6 to 20 in. in height and from 32 to 46 days old, are, if anything, more susceptible than alfalfa which has been established for several years. With these seedlings, treatments with 0.75 p.p.m. caused the appearance of first symptoms of injury in four hours when the humidity was 30 to 40%, and in two hours when the humidity was 65 to 90%. Four-hour fumigations under these conditions produced more injury on the seedlings than similar treatments on alfalfa that had been established for several years. Again, seedlings 35 days old from the date of planting showed markings on 30% of the leaves when treated with concentrations of 1.50 p.p.m. for 2.5 hr. at 42% relative humidity.

In experiments on a stand established for several years, the plants being 12 days old from the last date of cutting, an average concentration of 2.05 p.p.m. for six hours caused injury on only 25% of the leaves under similar humidity conditions.

Alfalfa plants at all stages of growth appear to be quite resistant to killing by sulphur dioxide gas. In all the experiments carried out at Summerland, B.C., the writers did not encounter a single case where an alfalfa plant had been killed by sulphur dioxide. Even in those cases where over 50% of the leaf tissue was marked on a plant there was no indication of any killing of either the plant or of individual shoots on the same plant. The effect of the gas where the treatment had resulted in appreciable leaf destruction was manifest only in a retardation in growth or diminution in crop yield.

In the case of seedling alfalfa plants less than 6 in. in height, which sustained 40% leaf destruction after treatment with sulphur dioxide, the plants showed remarkable recovery and after a few weeks could scarcely be distinguished from the surrounding control plots.

THE ABSORPTION OF SULPHUR DIOXIDE BY ALFALFA

The extent of absorption of sulphur dioxide by alfalfa leaves is dependent upon various internal and external factors, among which concentration of gas in atmosphere, duration of the treatment, and turgidity of the leaves are very important.

High rates of absorption of sulphur dioxide by leaves are found generally when active photosynthesis has taken place, stomata are fully open, and the soil moisture is adequate for the plant requirements. The peak of absorption coincides with the period of the day when plant activity is at a maximum. Thus the peak of absorption for alfalfa is generally reached some time during the period of the day between 8.00 a.m. and early afternoon. The rate of absorption falls off in the late afternoon and throughout the night it remains at a low level. In a continuous fumigation with sulphur dioxide gas the rate of absorption by the alfalfa plants closely parallels the movement of the stomata, and the high and low levels correspond to the peaks of photosynthesis and respiration, respectively.

The data in Tables V, VI, and VII indicate the rates of absorption of 6 by 6 ft. plots of alfalfa containing 90 plants under various environmental conditions. The results in Table V indicate that with concentrations in the neighborhood of 1.00 p.p.m., during a continuous 21 hr. fumigation, from 10 a.m., July 27, to 7 a.m., July 28, the rate of absorption was quite high in the morning, began to fall off in the early afternoon and was maintained at a low level throughout the remainder of the day and night until early the following morning. A part of the reduction in the rate of absorption which is evident after about two hours' treatment is probably due to the influence of concentrations of gas of this magnitude in effecting both a partial closure of the stomata and a reduction in the carbon dioxide assimilation.

The data in Table VI show the effect of simultaneous sulphur dioxide treatments with similar concentrations on two plots of alfalfa, one in which the soil moisture maintained was adequate (12.8%) and the plants were in a turgid condition; and the other containing plants at the wilting point with the soil moisture 6.2%. A marked difference is shown in the rate of absorption of the turgid plants in comparison with those at the wilting point, the latter absorbing a much lower quantity of gas compared to the former. The effects of the gas treatments, consisting of 21% of marked leaves in the case of the turgid plot and no injury at all in the dry plot, are readily explained by the absorption data.

Table VII shows the results obtained on the rate of absorption of two plots of alfalfa fumigated simultaneously, but one of which was shaded, so that during the period of maximum light the shaded cabinet received only 200 ft. candles of illumination compared with 6,000 ft. candles for the cabinet exposed to sunlight. The plants in the shaded cabinet did not show as high a rate of absorption as those in the exposed cabinet during the first day's treatment, and this was particularly evident during the period up to 6 p.m. The first symptoms of injury appeared on Plot H-5, the one exposed to full sunlight, at 4 p.m. No symptoms were visible at that time on the shaded plot. Very little absorption was registered during the night but the following morning, owing to the fact that the plot in full sunlight had been marked to the extent of 35% of its leaves, the rate of absorption was somewhat lower than that of the shaded plot, where the sulphur dioxide injury amounted to only 11%.

TABLE V
THE ABSORPTION OF SULPHUR DIOXIDE BY ALFALFA

Time	Sulphur dioxide treatment			Temperature, °F	Humidity, %
	Intake, p.p.m.	Exit, p.p.m.	Absorption, %		
July 27, 1936					
10.00 a.m.—10.30 a.m.	0.88	0.69	21.6	86	56
10.30 a.m.—11.00 a.m.	1.36	1.10	19.1	86	54
11.00 a.m.—11.35 a.m.	0.86	0.71	17.4	90	50
11.35 a.m.—12.10 p.m.	0.86	0.75	12.7	90	48
12.10 p.m.— 1.10 p.m.	0.94	0.90	4.2	91	42
1.10 p.m.— 2.00 p.m.	1.03	1.00	2.9	93	41
2.00 p.m.— 3.00 p.m.	1.11	1.10	0.8	90	41
3.00 p.m.— 4.00 p.m.	1.11	1.10	0.8	88	40
4.00 p.m.— 6.30 p.m.	1.11	1.10	0.8	—	—
6.30 p.m.—10.30 p.m.	1.38	1.31	5.1	59	79
10.30 p.m.—12.00 m.n.	1.30	1.26	3.1	58	80
July 28, 1936					
12.00 m.n.— 3.30 a.m.	1.23	1.20	2.5	56	82
3.30 a.m.— 5.30 a.m.	1.08	1.05	2.8	55	79
5.30 a.m.— 7.00 a.m.	1.25	1.12	10.4	62	60

TABLE VI
THE ABSORPTION OF SULPHUR DIOXIDE BY ALFALFA

Time	Sulphur dioxide treatment			Temperature, °F.	Humidity, %
	Intake, p.p.m.	Exit, p.p.m.	Absorption, %		

<i>Plants turgid—soil moisture 12.8%</i>					
July 30, 1936					
11.00 a.m.—12 noon	0.85	0.63	25.9	95	48
12 noon — 1.30 p.m.	0.86	0.66	23.3	95	38
1.30 p.m.— 2.30 p.m.	0.92	0.74	19.6	95	36
2.30 p.m.— 3.30 p.m.	1.08	0.90	16.7	95	36
3.30 p.m.— 5.30 p.m.	1.17	1.00	14.6	94	66
5.30 p.m.—12.00 m.n.	1.05	0.96	8.6	78	55
July 31, 1936					
12.00 m.n.— 3.00 a.m.	0.89	0.83	6.7	61	60
3.00 a.m.— 6.00 a.m.	0.84	0.80	4.7	62	63
6.00 a.m.— 7.00 a.m.	0.87	0.74	15.0	76	58
7.00 a.m.— 7.30 a.m.	1.15	0.96	16.6	88	56
7.30 a.m.— 8.30 a.m.	0.84	0.72	14.4	100	51
8.30 a.m.— 1.45 p.m.	0.78	0.69	11.6	100	51

<i>Plants wilting—soil moisture 6.2%</i>					
July 30, 1936					
11.00 a.m.—12 noon	0.95	0.84	11.6	90	50
12 noon — 1.30 p.m.	0.95	0.84	11.6	90	55
1.30 p.m.— 2.30 p.m.	0.95	0.84	11.6	91	48
2.30 p.m.— 3.30 p.m.	1.03	0.99	3.9	92	45
3.30 p.m.— 9.00 p.m.	1.03	0.99	3.9	85	58
9.00 p.m.—12.00 m.n.	0.96	0.91	5.2	72	55
July 31, 1936					
12.00 m.n.— 2.00 a.m.	0.84	0.80	4.7	68	60
2.00 a.m.— 7.00 a.m.	0.76	0.72	5.2	65	62
7.00 a.m.— 7.30 a.m.	0.80	0.78	2.5	90	57
7.30 a.m.— 9.00 a.m.	0.97	0.90	7.2	100	53
9.00 a.m.—12 noon	0.90	0.86	4.4	100	50

INFLUENCE OF LIGHT ON SUSCEPTIBILITY

Since light plays a very important role in determining plant activity it seemed reasonable to expect that plants would respond differently to sulphur dioxide depending on the intensity of the illumination. It is known too, from the work of other investigators and from observations in smelter-fume areas, that plants are more susceptible in daylight than at night. During the course of our studies on both barley and alfalfa, experiments were carried out to determine this effect as accurately as possible.

TABLE VII
THE ABSORPTION OF SULPHUR DIOXIDE BY ALFALFA

Sulphur dioxide treatment						
Plot G-11—Cabinet completely shaded				Plot H-5—Cabinet in full sunlight**		
Time	Intake, p.p.m.	Exit, p.p.m.	Absorption, %	Intake, p.p.m.	Exit, p.p.m.	Absorption, %
August 12, 1936						
8.30 a.m.—9.25 a.m.	0.68	0.52	23.5	0.65	0.43	33.8
9.25 a.m.—10.30 a.m.	0.76	0.58	23.7	0.87	0.62	28.8
10.30 a.m.—11.35 a.m.	0.84	0.66	21.4	0.67	0.44	34.3
11.35 a.m.—12.40 p.m.	0.80	0.66	17.5	0.79	0.50	36.7
12.40 p.m.—1.50 p.m.	0.82	0.72	12.2	0.90	0.54	40.0
1.50 p.m.—2.55 p.m.	0.91	0.79	13.2	0.90	0.58	35.6
2.55 p.m.—4.00 p.m.	0.94	0.82	12.8	0.99	0.62	37.4
4.00 p.m.—5.00 p.m.	0.95	0.82	13.7	0.90	0.68	24.4
5.00 p.m.—6.00 p.m.	0.99	0.85	14.2	0.98	0.77	21.4*
6.00 p.m.—8.00 p.m.	0.95	0.87	8.4	1.02	0.90	11.7
8.00 p.m.—10.00 p.m.	0.91	0.86	5.5	1.00	0.93	7.0
10.00 p.m.—12.00 m.n.	0.82	0.80	2.5	1.00	0.96	4.0
August 13, 1936						
12.00 m.n.—1.30 a.m.	0.73	0.70	4.2	0.95	0.92	3.2
1.30 a.m.—3.00 a.m.	0.78	0.76	2.5	0.87	0.85	2.4
3.00 a.m.—4.40 a.m.	0.74	0.72	2.8	0.76	0.73	3.9
4.40 a.m.—5.50 a.m.	0.60	0.60	0.0	0.73	0.66	9.6
5.50 a.m.—6.50 a.m.	0.74	0.59	20.3	0.87	0.73	16.1
6.50 a.m.—7.55 a.m.	0.80	0.62	22.5	0.88	0.73	17.1
7.55 a.m.—9.00 a.m.	0.85	0.62	27.1	0.84	0.69	17.8
9.00 a.m.—10.00 a.m.	0.90	0.65	27.8	0.84	0.69	17.8
10.00 a.m.—11.10 a.m.	0.90	0.62	31.2	0.86	0.70	18.6
11.10 a.m.—1.30 p.m.	0.94	0.69	26.6	0.90	0.72	20.0

* Symptoms of injury appeared on leaves.

** At 10.30 a.m. the light in this cabinet was 6,000 ft-candles—in the shaded cabinet 200 ft-candles.

The average temperature and humidity were 87 °F. and 58% for Plot H-5 and 79 °F. and 61 % for Plot G-11.

Barley

With barley, in 1931, four series of experiments were made to determine the effect of sulphur dioxide fumigations at different periods of the day or night. The results of these are given in Table VIII. The first series, comprising Plots H-7, -8 and -10, was made on young barley plants 19 days old from the date of sowing, the average height of the plants being about 8.5 in. It is apparent from the results of this first series covering the period 7.30 a.m. to 5 p.m., that as far as markings are concerned there is little difference in the susceptibility of growing barley throughout the morning, mid-day and afternoon periods. The data on absorption of sulphur dioxide would seem to indicate that a smaller amount of gas taken up by the leaves in the morning may cause slightly more injury than a greater amount later in the day.

By extending the afternoon period of fumigation to include the early evening hours more striking differences in susceptibility were obtained. This is shown in the next series of experiments carried out three weeks later on the same plots. At this time higher concentrations of approximately 5.00 p.p.m. were used. Each fumigation lasted for a period of 3.5 hr., the first being from 8.15 to 11.45 a.m., the second from 12 noon to 3.30 p.m., and the third from 4.30 p.m. to 8 p.m. It is clear from these experiments that barley is much more susceptible in the morning than in the late afternoon, but there is only a small difference in response between morning and mid-day periods.

A third series of experiments dealing with the effect of light on susceptibility of barley included four treatments with concentrations of sulphur dioxide of about 1.50 p.p.m. for periods of 4 hr. and 30 min. The plants were 29 days old, about 15 to 18 in. in height, and in the 6th leaf stage. Plot M-7 was fumigated from 11 p.m. to 3.30 a.m. in complete darkness. The rate of absorption of sulphur dioxide was 4.7%, which is surprisingly high for night conditions. Observations taken on leaves at 2.00 a.m. indicated that about 50 to 60% of the stomata of the leaves were partially open on both fumigated and control plots. As this was a night run the temperatures were somewhat lower than in the daylight, being 70 to 79°F., but the relative humidity was quite low, not exceeding 40%. During the period, 4.30 to 9 a.m. the same morning, Plot M-9 was fumigated. From 5 a.m. to 6 a.m. the light intensity was of the order of 1,600 units, rising rapidly thereafter to 12,000 units at 9 a.m. The humidity was 52% for a period of 20 min. and then fell rapidly to 24%. The average rate of absorption was 4.8% of the intake concentration, and the condition of the stomata did not change until about 8 a.m., when the openings became larger. The third plot in this series, M-11, was fumigated from 9.30 a.m. to 2 p.m. The temperature rose from 92 to 104°F. and the humidity dropped from 26 to 20%. The light intensity was constant at 12,000 units. The stomata were wide open throughout the experiment, and correlated with this there was an increase in rate of absorption to 8.4% of the sulphur dioxide entering the cabinet. The last fumigation of the day was carried out on M-14 from 3.30 to

TABLE VIII
INFLUENCE OF LIGHT ON SUSCEPTIBILITY OF BARLEY TO SULPHUR DIOXIDE

Plot no.	Date of fumigation, 1931	Age from date of seeding, days	Concentration sulphur dioxide, p.p.m.	Time of day	Humidity %	Hours sunshine	Light intensity, arbitrary units	Duration to first symptoms injury, hr.	Absorption, SO ₂ , %	Leaf area injured, %
H-7	July, 9	19	2.38	7.30 a.m.—10.30 a.m.	41-50	8.9	10,000	—	5.7	20
H-8	July, 9	19	2.10	10.45 a.m.—1.45 p.m.	35-50	8.9	9,000	—	8.5	12
H-10	July, 9	19	2.17	2.05 p.m.—5.05 p.m.	36-50	8.9	8,000	—	—	20
H-7	July 31	41	5.17	8.15 a.m.—11.45 a.m.	34-40	13.7	12,000	1.75	2.4	75
H-8	July 31	41	4.97	12.00 noon—3.30 p.m.	30-36	13.7	12,000	2	—	65
H-10	July 31	41	5.06	4.30 p.m.—8.00 p.m.	28-30	13.7	Light decreasing towards evening	—	—	25
M-7	July 20	29	1.40	11.00 p.m.—3.30 a.m.	33-40	Night	0	No injury	4.7	No injury
M-9	July 21	29	1.53	4.30 a.m.—9.00 a.m.	34-52	14.5	4.30-6 a.m. 1,600 9 a.m. 12,000	4.5	4.8	Slight tip injury
M-11	July 21	29	1.43	9.30 a.m.—2.00 p.m.	20-26	14.5	12,000	4.5	8.4	Very slight
M-14	July 21	29	1.45	3.30 p.m.—8.00 p.m.	27-29	1.45	Light decreasing towards evening	No injury	2.5	No injury
M-7	Aug. 7	47	2.98	9.10 p.m., Aug. 7 4.10 a.m., Aug. 8	62-77	Night	0	—	0.75	5
M-9	Aug. 8	47	2.91	4.33 a.m.—11.35 a.m.	37-80	—	10,000 at 8 a.m.	—	4.8	15
M-14	Aug. 8	47	2.61	11.45 a.m.—6.45 p.m.	50-63	—	12,000	—	4.7	25

8 p.m. During this period the temperature dropped from 102 to 84°F. and the relative humidity remained quite constant between 27 and 29%. The light intensity was as high as in the previous experiment until about 5 p.m. when it began to decrease gradually. Stomata began to close shortly after this experiment started and the rate of absorption was only 2.5%, which was considerably lower than that registered during the night.

Both Plot M-7, fumigated in darkness, and Plot M-14, fumigated in the late afternoon, escaped injury. In the other plots there were slight tip injuries on the younger leaves. The results indicate that during the daily cycle of 24 hr. the period of greatest susceptibility of plants to sulphur dioxide coincides with the period of maximum light intensity and plant activity.

The last series of fumigations was carried out on Plots M-7, M-9 and M-14, in rotation, during a 24 hr. period, when the plants were 47 days old and in the head stage. Each plot was fumigated for seven hours at a concentration of almost 3.00 p.p.m. The first treatment was during the night from 9.10 p.m. to 4.10 a.m. The stomata were closed throughout most of the fumigation period and the absorption was only 0.75% of the gas passing into the cabinet. The second fumigation, on Plot M-9, covered the period from 4.35 a.m. to 11.35 a.m. Light intensity was approximately 10,000 units after 8 a.m. Stomata began to open soon after sunrise at 5.20 a.m., and the average absorption over this period was 4.8%. The third plot was treated from 11.45 a.m. to 6.45 p.m.

Although symptoms of injury appeared in all three plots, M-7, which was treated during the night, was least affected. The tips of the awns and the glumes on the side florets were bleached slightly; on the immature tillers there were slight markings on the shot blades, leaf sheaths and on the tips of the 7th and 8th leaves. Less than 5% of the total foliage on this plot was affected by the treatment. The second plot fumigated in the morning was injured much more severely. Injury was present on the awns, glumes and five upper leaves and also the leaf sheaths. About one-third of the area of the younger leaves was discolored and approximately 15% of the total leaf area was destroyed. The most severe markings were found on Plot M-14, fumigated from 11.45 a.m. to 6.45 p.m. The distribution of the markings was similar to those found on Plot M-9, but in some cases the injured portions involved more than one-half the leaf. Approximately 25% of the foliage on the plot was affected.

A comparison of the results of these three fumigations shows that the barley was least susceptible to sulphur dioxide during the night even though the average humidity was highest during this period. The period of fumigation from 11.45 a.m. to 6.45 p.m. was productive of more damage than that from 4.35 a.m. to 11.35 a.m. The average rate of absorption of sulphur dioxide by the plants was similar during both these periods, but the average concentration was 2.61 p.p.m. during the afternoon fumigation as against 2.91 p.p.m. during the morning fumigation. The other factors which rendered the barley more susceptible

during the afternoon fumigation than in the morning were the temperature, humidity and light. Full light intensity of 12,000 units prevailed during the seven hour afternoon period, whereas during the early part of the morning, 4.35 a.m. to 6.00 a.m., the light intensity was quite low. With regard to temperatures, those registered in the morning ranged from 51 to 86° F., but in the afternoon they rose from 86 to 93° F. The relative humidity was quite variable during the early morning, but the average over the whole morning period was definitely less than 50%. During the afternoon fumigation the humidity was maintained close to 60% by use of the humidity apparatus.

Some general conclusions may be drawn from the data of the 13 experiments shown in Table VIII. During clear, warm, summer weather, the susceptibility of growing barley to sulphur dioxide is fairly constant from about 7.30 a.m. to 3.30 p.m. From then onwards the susceptibility decreases coincident with the gradual closing of the stomata of the leaves. The resistance to sulphur dioxide is greatest during the night and is not influenced in this respect by humidity or rate of absorption of sulphur dioxide to the same extent as in daylight. With regard to the effect of morning fumigations as compared with early afternoon fumigations under similar conditions, barley plants are somewhat more susceptible to sulphur dioxide in the morning, but the evidence is not clear-cut on this point. The activity of the plant and condition of the stomata as indicated by rate of sulphur dioxide absorption are important in this connection. These remarks apply to plants growing under normal soil moisture conditions.

Alfalfa

It was apparent whenever fumigations were carried out at night that there was a great difference in susceptibility in comparison with those made in full daylight. In Table III these differences are clearly shown—thus at 0.50 p.p.m., 10 hr. were required to produce first symptoms of injury in daylight below 80% relative humidity, whereas approximately four times the duration was necessary in darkness. In other experiments at 0.75 p.p.m. the duration to produce injury in darkness was more than three times that in daylight. At 1.00 p.p.m. this difference ranged from 3 to 10 times the duration in light, and at concentrations of about 2.00 p.p.m. the differences between susceptibility in light and darkness were even greater. These experiments, however, were not controlled to determine the actual effect of light, and other factors may have been responsible for some of the wide variations in results. The effect of shading a cabinet and fumigating in daylight is shown in Table VII. It is apparent from these experiments that a lowering of the light intensity not only increases the time required to produce the first symptoms of injury but clearly reduces the amount of injury suffered in a definite length of time.

Two series of experiments which dealt especially with the effect of light were carried out in August, 1935. Quite high sulphur dioxide concentrations were employed as shown in Table IX. It was thus possible to conduct a series of ex-

TABLE IX

INFLUENCE OF LIGHT ON SUSCEPTIBILITY OF ALFALFA TO SULPHUR DIOXIDE
(Duration of fumigations—one hour)

Sulphur dioxide conc., p.p.m.	Time of day	Av. light, in foot candles	Absorption of sulphur dioxide ¹ , %	Percentage injured leaves	Percentage marked leaves
<i>Series I—August 23, 1935</i>					
3.3	3.00 a.m.— 4.00 a.m.	0	10	None	Slight
3.2	4.20 a.m.— 5.20 a.m.	0	9	None	Slight
3.3	5.30 a.m.— 6.30 a.m.	94.5	9.6	None	1
3.1	7.30 a.m.— 8.30 a.m.	2020	16.5	22	41
3.3	8.40 a.m.— 9.40 a.m.	2473	24.5	18	42
3.3	10.00 a.m.—11.00 a.m.	1360 (6700 for brief period)	19.0	13	34
<i>Series II—August 27-28, 1935</i>					
4.5	9.00 p.m.—10.00 p.m.	0	9.2	None	None
4.8	3.00 a.m.— 4.00 a.m.	0	9.1	None	Very slight
4.6	4.40 a.m.— 5.40 a.m.	65	11.5	None	Very slight
5.0	5.50 a.m.— 6.50 a.m.	300	15	None	16
4.8	7.30 a.m.— 8.30 a.m.	1500	25	22	42
4.6	8.45 a.m.— 9.45 a.m.	3135	32	31	51
4.9	10.30 a.m.—11.30 a.m.	4940	31	32	51
5.0	1.20 p.m.— 2.20 p.m.	3760	31	44	62
4.8	3.30 p.m.— 4.30 p.m.	1680	22	8	29
4.4	6.20 p.m.— 7.20 p.m.	50	12.5	None	Slight
4.5	9.30 p.m.—10.30 p.m.	0	9.5	None	None

¹ The figures in this column represent the percentage difference between the intake and exit concentrations of sulphur dioxide. The absorption by the cabinet and soil at this concentration is about 5%.

periments within a 24 hr. period. The first series of hourly experiments began at 3 a.m. and was carried on at intervals until 11 a.m. the same morning. The second series began at 9 p.m. in the evening and, in all, 11 experiments, each lasting one hour, at a concentration of from 4.50 to 5.00 p.p.m., were made at various intervals until 10.30 p.m. the following day. The effects of these treatments at different hours of the day or night are shown in Plate I. The fumigations which were carried out in complete darkness did not result in injury, the absorption of sulphur dioxide by the plants being quite low. The treatment carried out between 3.00 and 4.00 a.m. resulted in very slight markings, although the light was not measurable, and the percentage of absorption remained the same as in the treatment made in complete darkness. The hourly fumigation between 6.00 and 7.00 a.m. resulted in sulphur dioxide markings on about 16% of the leaves in the plot. The average light intensity was 300 ft. candles, and the absorption increased from 11.5% in the previous hour to 15%

during this hour. A pronounced change in susceptibility occurred between 7.30 and 8.30 a.m. At this time the average light intensity was about 1,500 ft-candles, but the absorption increased from about 9 to 25%, and substantial injury, consisting of markings on 42% of the leaves, was produced. During the next hourly treatment (8.45 to 9.45 a.m.) the light intensity continued to increase, the percentage of gas absorption increased, and also the percentage of marked leaves. Following this (10.30 to 11.30 a.m.), although the light increased considerably, both the absorption and extent of injury remained the same, indicating that light was no longer a factor. The next marked change in susceptibility occurred at 3.30 to 4.30 p.m. During this hour the light, gas absorption and percentage of marked leaves decreased. The gas treatment during the hour 6.20 to 7.20 p.m. produced only a very slight effect in comparison with that produced by the early morning treatment between 5.00 and 6.00 a.m. The last treatment during 9.30 to 10.30 p.m. was carried out without producing any injury whatever, this result being in accord with that obtained the previous night. It would appear, therefore, that the morning and early afternoon is the most susceptible period of the day for alfalfa plants. Furthermore, light in excess of about 3,000 ft-candles does not appear to have any marked influence on susceptibility. Below this value a drop in light intensity results in a decrease in the absorption of gas by the plants, with a consequent increase in resistance to sulphur dioxide injury.

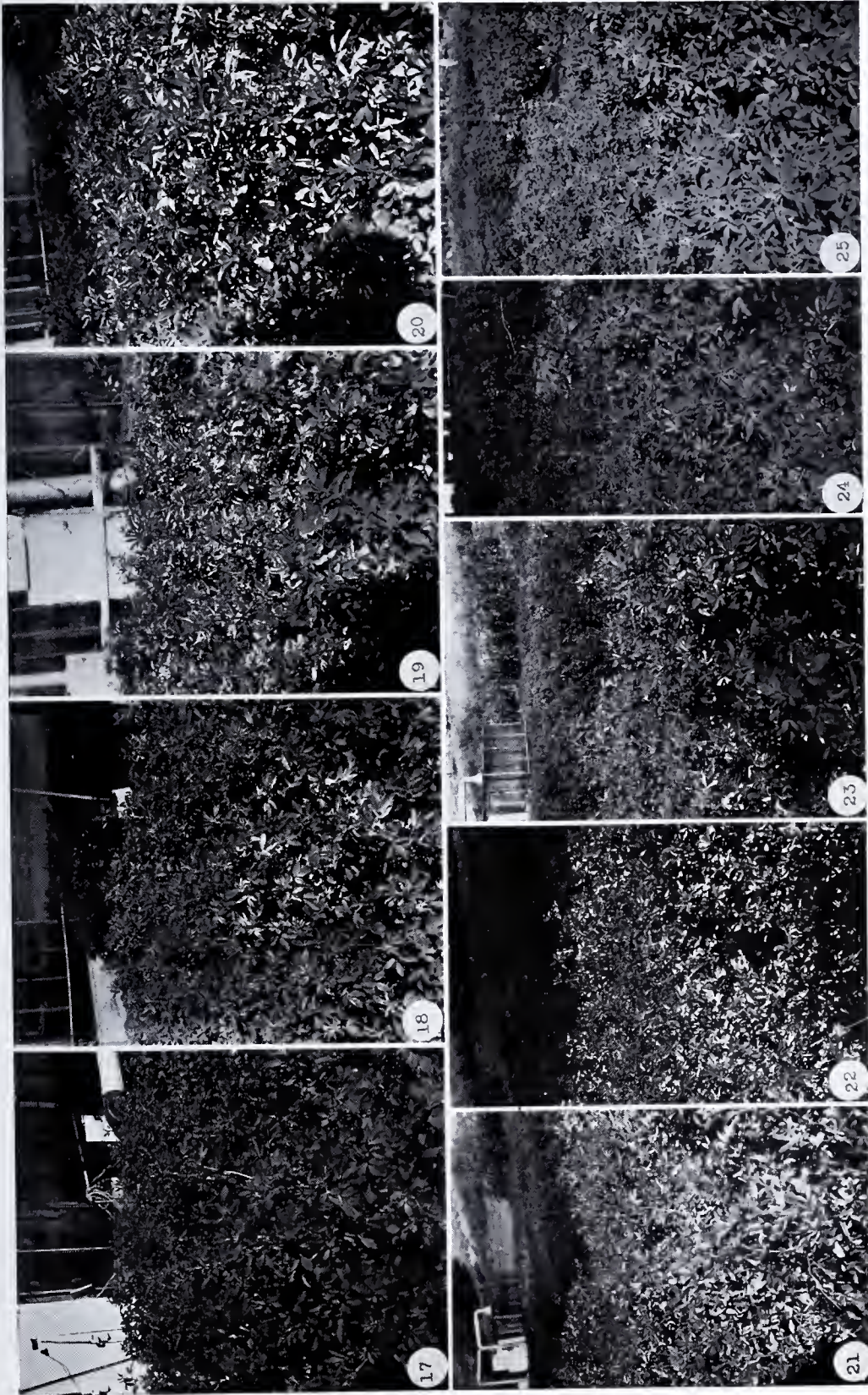
THE INFLUENCE OF SOIL MOISTURE ON SUSCEPTIBILITY

It was noticed frequently during the course of the field studies in the area surrounding the Trail smelter that markings from sulphur dioxide were seldom found on crop plants growing under very dry conditions. During the course of the experimental work a number of experiments on both alfalfa and barley were made in order to compare the susceptibility of these plants growing under conditions of very low soil moisture with those where the moisture was adequate for normal growth. In dry plots irrigation was withheld until the plants showed signs of wilting. Soil moisture determinations were then made on these plots and adjacent well watered plots. It was found that where the soil moisture fell below 5 or 6% the plants wilted during part of the day at least.

Barley

The results of treating barley grown on such plots with sulphur dioxide are shown in Table X. Two series of experiments were carried out, each series consisting of one plot with low soil moisture and another similar plot where the moisture was adequate for growth. Both plots were fumigated with similar concentrations of sulphur dioxide simultaneously. Plot K-11 was fumigated with 1.2 p.p.m. for 14 hr. without injury. Plot K-9, which received the same treatment, was injured after 12 hr. and 35 min., and at the end of the treatment 5% of the leaf area was marked. There was a very great difference in the rate of

PLATE I



Effect of sulphur dioxide under various light conditions. FIG. 17, Plot F-9, 4.58 p.m., 4.40-5.40 a.m., August 28, FIG. 18, Plot F-11, 5.03 p.m., 5.50-6.50 a.m., August 28, FIG. 19, Plot F-13, 4.81 p.m., 7.30-8.30 a.m., August 28, FIG. 20, Plot F-15, 4.63 p.m., 8.45-9.45 a.m., August 28, FIG. 21, Plot D-19, 4.89 p.m., 10.30-11.30 a.m., August 28, FIG. 22, Plot D-18, 4.97 p.m., 1.20-2.20 p.m., August 28, FIG. 23, Plot D-16, 4.85 p.m., 3.30-4.30 p.m., August 28, FIG. 24, Plot D-14, 4.40 p.m., 6.20-7.20 p.m., August 28, FIG. 25, Plot F-5, 4.55 p.m., 9.00-10.00 p.m., August 27.

TABLE X
INFLUENCE OF SOIL MOISTURE ON THE SUSCEPTIBILITY OF BARLEY
TO SULPHUR DIOXIDE

Plot	Soil moisture		Humidity %	Age of plants, days	Sulphur dioxide treatment				Leaf area injured, %
	Depth, in.	Moisture, %			Date	Conc., p.p.m.	Duration, hr.	Absorption, %	
Dry-K-11	0-6	1.7	20-46	40-41	Aug. 19	1.23	9.5	1.29	No injury
	6-12	4.5			Aug. 20	1.26	4.5	.52	
	12-24	1.7							
Wet-K-9	0-6	11.1	28-50	40-41	Aug. 19	1.20	9.5	10.8	5
	6-12	9.2			Aug. 20	1.28	4.5	9.84	
	12-24	9.6							
Dry-K-13	0-6	2.1	23-33	42	Aug. 21	2.02	7	nil	No injury
	6-12	3.6							
	12-24	1.9							
Wet-K-8	0-6	16.2	28-39	42	Aug. 21	1.9	7	3.55	15
	6-12	16.6							
	12-24	17.7							

absorption of sulphur dioxide between the dry and the wet plots. Thus, for K-11 the absorption was 1.29% for part of the treatment, whereas for K-9 it was 10.8%. The soil moisture of the wet plot was 11.1% in the top 6 in. compared with 1.7% in the case of the dry plot. The stomata on the plants in the dry plot were almost completely closed.

The second series consisted of a dry plot, K-13, with soil moisture of 2.1% in the top 6 in. of soil, in comparison with plot K-8 which had a soil moisture of 16.2% for the same depth. An average concentration of approximately 2.0 p.p.m. was maintained for seven hours on both plots. The dry plot showed practically no absorption of sulphur dioxide during the experiment, the stomata of the leaves being completely closed. For K-8, however, the absorption was 3.55% of the gas entering the cabinet. On this plot the first symptoms of injury appeared after four hours of fumigation, and 15% of the leaf area was finally injured, but no injury whatever was noted on the dry plot. These experiments indicate that barley in a wilted condition is extremely resistant to sulphur dioxide. Probably the main factor in inducing resistance is the condition of the stomata, which were invariably found to be closed, or nearly closed, when the soil moisture reached the wilting point.

Alfalfa

Most of the experiments on the influence of soil moisture on susceptibility were made on the alfalfa plots, and the data are shown in Table XI. The experiments were carried out in the same manner as with barley. Plot Y-1, with a soil moisture of 4% in the top 15 in. of soil and Plot X-1 with a soil moisture of 12.5% at the same depth, were treated with 0.70 p.p.m. of sulphur dioxide for 24 hr. On the dry plot the plants in the border rows showed signs of wilting and the remainder of the plants were very close to the wilting point. At the conclusion of the experiment there were only a few leaves with small intercostal markings found on the dry plot, whereas on the wet plot 15% of the leaves were marked. In an experiment with concentrations of 0.91 to 0.94 p.p.m., lasting 25 to 26 hr., it was found that 21% of the leaves were injured on the wet plot, whereas on the dry plot no injury appeared. When the humidity was maintained at 68% a treatment with 0.50 p.p.m. for one hour, followed by 1.00 p.p.m. for three hours, caused markings to appear on both wet and dry plots. On the wet plot 48% of the leaves were marked compared with 20% on the dry plot. The soil moisture on the dry plot was 4% and most of the plants were near the wilting point, some actually being wilted. It is apparent that by artificially raising the humidity of a very dry plot it is possible to produce markings, though not as easily as in the case of a plot where soil moisture is adequate for good growth.

The soil moisture, when maintained near the wilting point of the plants, exerts a very profound influence on the susceptibility of the plants to sulphur dioxide. On the other hand, when the moisture is adequate for growth, varia-

tions in soil moisture within wide limits do not appreciably affect the susceptibility of the plant. The experiments shown in Table XI indicate very clearly that even when soil moisture is low, humidity plays a very important part. Thus, the only dry plots on which appreciable markings were obtained were those in which the humidity was over 55%.

TABLE XI
INFLUENCE OF SOIL MOISTURE ON THE SUSCEPTIBILITY OF ALFALFA
TO SULPHUR DIOXIDE

Plot no.	Soil moisture, depth 1-15 in. %	Sulphur dioxide treatment		Humidity, %	Percentage of leaves marked
		Concentration, p.p.m.	Duration, hr.		
X-1 Wet	12.5	0.70	24.0	40-75	15
Y-1 Dry	4.0	0.70	24.0	40-75	0
G-20 Wet	12.8	0.94	26.75	52	21
E-8 Dry	6.2	0.91	25.0	54	0
X-2 Wet	12.5	0.50)	1)	68	48
		1.00)	3)		
Y-2 Dry	4.0	0.50)	1)	68	20
		1.00)	3)		
H-15 Wet	15.6	1.32	4	59	11
F-15 Dry	6.4	1.30	4	57	6
H-13 Wet	14.4	1.87	2	60	40
F-13 Dry	6.7	1.81	2	59	10
G-14 Wet	15.1	1.91	6	36	17
E-4 Dry	3.7	1.91	6	35	0
G-16 Wet	17.7	2.05	6	30	35
E-16 Dry	4.0	2.10	6	33	0
X-3 Wet	12.5	2.25	12.5	35-60	42
Y-3 Dry	4.0	2.25	12.5	55-60	Very few

SUSCEPTIBILITY OF BARLEY IN SMELTER-FUMES AREA COMPARED WITH THAT UNDER EXPERIMENTAL CONDITIONS

The question frequently arises as to how far conclusions drawn from the results of experimental fumigations under cabinets may be applied to plants growing under natural field conditions in a smelter zone. In 1931 an attempt was made to apply, experimentally, to a crop at Summerland a series of fumigations as nearly as possible identical with those occurring at the Stroh farm plots in the Northport area. The sulphur dioxide and meteorological records taken at the Stroh farm were sent to Summerland every few days, and similar conditions of fumigation were then imposed there on the barley set aside for this

purpose. In order to maintain temperature and humidity factors as nearly comparable as possible, a few fumigations relayed from the Stroh farm were not repeated until some later date when weather conditions at Summerland chanced to be more favorable. It was usual, however, to repeat a fumigation at Summerland about three days later than it actually occurred on the Stroh plots. Owing to the effect of the fumigation cabinet, temperatures were somewhat higher at Summerland than those recorded at the Stroh farm. The humidity was maintained as closely as it was possible to that obtaining in the Northport area. There was a difference of only three days in the age of the barley at the two localities, and the fumigations covered a period of about 40 days. The experimental data have been arranged side by side for convenient comparison in Table XII.

Both at Summerland and on the Stroh plots the barley was sown by hand and spaced so that seedlings would be about 3 in. apart. Each plot contained 11 rows, 12 ft. in length. At both locations ample irrigation was supplied throughout the growing period.

As all the relevant data are presented in Table XII, only a few remarks need be made on the significance of the results. In comparing the injuries present on the Stroh barley with those of the Summerland plots, only the plants in the special plots set aside for this purpose should be considered. The markings which occurred on rye and other cereals grown on the Stroh plots have been presented to show the relative susceptibility of these in comparison with barley. It is interesting to note that the first fumigation to produce injury on the Stroh-plot barley was also responsible for initial injury at Summerland. This fumigation took place on June 14 to 16 at the Stroh farm and was repeated at Summerland on June 17 to 19. The barley was 31 and 30 days old at this time at the respective stations. At this time the plants had received approximately 124 hours' sulphur dioxide treatment and the average concentration was about 0.29 p.p.m., with a maximum of 1.05 p.p.m., at Summerland. After these initial symptoms fresh injury appeared on four different occasions, both at Summerland and the Stroh farm. In general, the injury was slightly more severe on the plots at Summerland than on those at the Stroh farm in the Northport area. At the conclusion of the experiment the plants under the cabinet at Summerland had been treated with sulphur dioxide for 213 hr. and 50 min., and both the duration and range of concentrations were comparable to those recorded at the Stroh plots.

Owing to the injury sustained by the plants, there was a reduction in the amount of straw produced on the fumigated plot at Summerland, but the yield of grain was not affected. While definite conclusions cannot be drawn from one plot, other fumigation studies on growing barley subsequently confirmed these results.

It is interesting to note that the increase in sulphur content of the leaves on the Stroh farm plots and at Summerland were of the same order. Thus, on June 7, 1st and 2nd leaves contained 1.17, 3rd leaf 0.97, and 4th and 5th leaves 0.47% sulphur on the Stroh plot. At Summerland on June 9, 1st and 2nd leaves had 0.97, 3rd leaf 0.59 and 4th and 5th leaves 0.44% sulphur. On June 25, whereas at Stroh plots 1st, 2nd and 3rd leaves averaged 1.22% sulphur, at Summerland for the same leaves the percentage was 1.37; this indicates that the plants at Summerland were slightly more active in absorbing and accumulating sulphur.

The results of this experiment indicate clearly that the response of plants to sulphur dioxide under natural conditions is not essentially different from that found in fumigations under cabinets.

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TABLE XII—COMPARATIVE SUSCEPTIBILITY OF

Stroh Farm								
Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
May 22	6	4.00—9.00	0.06	—	56	48	Cloudy, sunlight	Seedlings just appearing above ground. Leaves not expanded. No SO ₂ markings on alfalfa on Stroh plot
		9.00—15.20	.06	—	59	55		
		15.20—18.00	.12	—	61	54		
		18.00—18.40	.22	0.27	53	76		
		18.40—19.40	Trace	—	53	77		
		19.40—24.00	.20	.36	51	80		
May 23	7	0.00—3.00	0.22	0.31	47	82	Bright sunlight	No marking
		3.00—6.00	.22	.31	47-54	82-65		
		6.00—9.40	.17	.24	54-71	65-28		
		9.40—11.20	Trace	—	73	25		
May 24	8	6.20—7.00	Trace	—	58-62	45-37	Occasional clouds, sunlight 60% day	No marking
		7.00—7.40	0.16	—	62-67	37-30		
		8.00—8.20	.87	1.25	71	29		
		8.20—10.40	.35	0.44	71-78	29-18		
		10.40—12.00	.05	—	78-85	17		
May 26	10	7.20—8.40	0.06	—	62-66	37-30	Bright sunlight	No marking
		8.40—11.00	.29	0.36	66-70	28		
		11.00—12.00	.06	—	70-73	24		
		12.00—13.00	Trace	—	74	24		
May 28	12	7.20—8.00	Trace	—	55-59	41	Bright sunlight	Slight marking on rye
		8.00—8.20	0.19	—	62	37		
		8.20—10.20	.40	0.46	67	30		
		10.20—11.20	.25	.29	75	18		
		11.20—12.40	.12	—	82	20		
May 29	13	7.10—7.50	0.25	0.31	64	36	Bright sunlight	Approx. 10% of the rye plants marked
		7.50—9.10	.50	.62	65-70	35-29		
		9.10—10.10	.26	.29	70-77	29-20		
		10.10—10.50	.14	—	77-84	21		
		10.50—11.10	Trace	—	—	—		
May 30	14	7.00—7.20	0.52	—	65	38	Cloudy 50% of the daytime	No marking
		7.20—7.40	.34	—	—	—		
		7.40—8.00	.99	—	70	35		
		8.00—8.40	.52	0.56	—	—		
		8.40—9.20	.32	.36	75	32		
		9.20—10.00	.14	.18	78	30		
		10.00—11.00	Trace	—	82	25		

BARLEY UNDER FIELD AND EXPERIMENTAL CONDITIONS

Plot B-5, Summerland								
Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
May 29	9	16.10—18.15	0.20	0.31	90	18	Bright sunlight, 2,500 at 18.00	Plants appeared above ground May 26. Now $3\frac{1}{2}$ -4 in. in height and in 2nd leaf stage
		18.15—20.10	.25	.27	84-67	25		
		20.10—24.15	.28	.32	64	25		
May 30	10	0.15— 3.15	0.37	0.44	61	25	Bright sunlight.	Plants under cabinets were about $\frac{1}{2}$ in. higher than those in outside control plots. No injury as a result of fumigation
		3.15— 6.00	.33	.36	61-66	25		
		6.00— 9.30	.37	.43	66-94	26		
		9.30—11.00	.22	.23	96	32		
June 1	12	9.00— 9.30	0.19	—	97	25	14,000 units Very bright sunlight	No injury. Plants in cabinets taller than those in outside control plots
		9.30—10.30	.80	0.86	102	27		
		10.30—11.00	.92	1.05	100	29		
		11.00—11.10	.61	—	—	—		
		11.10—12.10	.38	.40	104	26		
		12.10—12.40	.18	—	103	27		
June 2	13	9.00—10.00	0.18	0.25	70	33-40	Cloudy, 4,500 units	No injury
		10.00—11.00	.35	—	71-82	33		
		11.00—12.00	.20	.21	82-86	32		
		12.00—13.00	.16	—	88	30		
June 4	15	9.00— 9.30	0.08	—	83	48	Bright sunlight, 12,000 units	Plants in third leaf stage. Tip-burn from heat in both control and fumigated cabinets
		9.30—10.20	.19	—	84	44		
		10.20—11.25	.38	0.44	87	40		
		11.25—11.45	.51	.57	—	—		
		11.45—12.55	.27	.32	89	39		
		12.55—13.25	.11	—	96	39		
		13.25—14.20	.08	—	97	37		
June 5	16	7.40— 8.20	0.30	—	77	44	Bright sunlight, 12,000 units	No injury. Plants in cabinets taller than outside controls
		8.20— 8.50	.46	—	—	—		
		8.50— 9.20	.57	0.60	80	40		
		9.20—10.00	.49	.55	84	38		
		10.00—11.00	.25	—	87	37		
		11.00—11.30	.11	—	89	38		
June 6	17	8.05— 8.20	0.17	—	74	54	Cloudy, dull, 2,600 units	No effect of fumigations
		8.20— 8.40	.65	—	77	52		
		8.40— 9.00	.91	—	—	—		
		9.00— 9.20	.51	—	78	53		
		9.20—10.15	.28	0.31	81	44		
		10.15—11.00	.15	.19	—	—		

TABLE XII—COMPARATIVE SUSCEPTIBILITY OF

Stroh Farm								
Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
May 31	15	6.40—7.00	0.16	—	—	—	Clear, bright sunlight	No injury
		7.00—7.20	.33	—	70	42		
		7.20—7.40	.52	—	—	—		
		7.40—8.20	.76	0.82	74	36		
		8.20—9.20	.54	.58	80	30		
		9.20—10.20	.35	.42	84	20		
		10.20—11.00	.16	—	—	—		
		11.00—11.40	Trace	—	91	20		
June 1	16	5.20—6.00	0.10	—	55-60	54-50	Clear, bright sunlight	More injury occurred on the irrigated rye plot. $\frac{1}{8}$ in. marks on tips of leaves of 30% of plants
		6.00—6.40	.39	0.41	62	45		
		6.40—7.40	.60	.66	65-70	40		
		7.40—9.20	.28	.36	70-77	40-32		
		9.20—11.00	.10	.14	80	30		
		11.00—11.40	Trace	—	82	27		
June 3	18	6.20—6.40	0.13	—	49	65	Clear, bright sunlight	No injury
		6.40—7.00	.31	—	53	60		
		7.00—7.40	.52	0.56	55	53		
		7.40—8.40	.66	.69	—	50-40		
		8.40—9.20	.53	—	60	40-35		
		9.20—10.20	.27	.30	65	35-30		
		10.20—11.20	.12	.16	70	30-24		
		11.20—12.00	Trace	—	75	24-18		
June 4	19	5.40—7.00	0.26	0.33	47-55	62-40	Bright sunlight	No injury
		7.00—8.00	.16	.18	55-62	40-37		
		8.00—9.20	.10	.12	62-65	37-30		
		9.20—10.00	Trace	—	65-70	30-22		
June 5	20	6.40—7.40	0.06	—	55-59	49-40	Clear, bright sunlight	No injury
		7.40—8.10	.84	0.87	62	38		
		8.10—8.20	.58	—	—	—		
		8.20—9.20	.34	.40	62-66	35		
		9.20—10.20	.17	.19	66-71	35-30		
		10.20—11.20	.12	—	71-76	30-21		
		11.20—12.20	Trace	—	76-82	21-17		
June 6	21	6.40—7.20	0.25	0.30	55	56-52	Clear, bright sunlight	No injury
		7.20—8.20	.69	.73	55-64	52-39		
		8.20—9.00	.37	.42	64-69	39-35		
		9.00—9.40	.26	—	71	33		
		9.40—11.40	.13	.16	72-81	33-22		
		11.40—12.40	.04	—	81-88	22-16		
June 7	22	5.00—7.00	0.02	—	58	65	Bright sunlight	Marking on irrigated rye, but very slight
		7.00—8.20	.12	—	60-65	60-45		
		8.20—9.20	.69	0.74	65-70	40		
		9.20—10.00	.32	.39	72	38		
		10.00—13.00	.14	.20	72-80	38-20		

ENVIRONMENTAL FACTORS AND SUSCEPTIBILITY

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BARLEY UNDER FIELD AND EXPERIMENTAL CONDITIONS

Plot B-5, Summerland

Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
June 7	18	8.20—8.42	0.12	—	82	49	Bright sunlight. 12,000 units	No injury
		8.42—8.58	.50	—	83	47		
		8.58—9.44	.71	0.78	86	43		
		9.44—10.46	.52	.56	92	38		
		10.46—11.20	.43	—	93	35		
		11.20—12.26	.23	.28	94	—		
		12.26—12.40	Trace	—	97	31		
June 8	19	7.45—7.57	0.09	—	87	35	Bright sunlight. 10,000 units	No injury
		7.57—8.10	.24	—	89	34		
		8.10—8.40	.41	—	—	—		
		8.40—9.42	.60	0.63	95	30		
		9.42—10.20	.45	—	95	30		
		10.20—11.25	.34	—	96	29		
		11.25—13.00	.19	—	96	30		
June 9	20	8.45—9.25	0.28	0.31	80	47-40	9,000 up to 12 noon. Dull, cloudy afternoon, 12.00-14.00 2,500 units	No injury. Some tip burn injury present. First and second leaves in both control and fumigated plot turning yellow
		9.25—10.05	.36	.41	85	36		
		10.05—10.45	.52	.55	88	35		
		10.45—11.45	.61	.66	94-98	32-30		
		11.45—13.05	.28	.32	100-84	27-37		
		13.05—13.45	.10	—	84	37		
		13.45—14.05	Trace	—	77	44		
June 10	21	8.00—8.40	0.14	0.18	66	60	Clear, occasional clouds, 4,800 up to 9.00 a.m., 9.00-12.00 12,000 units	Very few plants with yellow leaves were found in outside control plots at this time
		8.40—9.00	.40	—	67-70	58-54		
		9.00—9.20	.10	—	70-80	54-44		
		9.20—10.20	.26	.31	80-84	44-30		
		10.20—11.40	.11	—	84-88	30-28		
		11.40—12.00	Trace	—	88-80	30		
June 11	22	7.55—8.25	0.07	0.10	82	34	Partially cloudy 8.05-9.45, 12,000 9.45-12.30, 6,000 units	Plants under cabinets more spindly and not stooling out as well as the outside controls. No injury by SO ₂
		8.25—9.05	.30	—	89-92	33		
		9.05—9.45	.81	1.00	84	38		
		9.45—10.45	.37	0.42	83	35		
		10.45—11.25	.28	.30	79	37		
		11.25—12.05	.13	.16	78	40		
		12.05—12.25	.02	—				
June 12	23	8.00—8.40	0.28	0.36	81	41	Bright sunlight, 12,000 units	No injury or marking by SO ₂
		8.40—10.00	.68	.75	82	40		
		10.00—10.20	.51	—	82-86	42		
		10.20—11.20	.26	.29	87	38		
		11.20—13.00	.12	.18	84	35		
		13.00—13.20	.08	—				
June 13	24	7.20—8.00	0.11	—	72	56-49	Cloudy till 9.30, then bright sunlight. 12,000 units	No injury
		8.00—9.15	.40	0.59	74	51		
		9.15—10.00	.68	.77	79	44		
		10.00—12.40	.19	.34	84-96	38-34		

TABLE XII—COMPARATIVE SUSCEPTIBILITY OF

Stroh Farm								
Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
June 8	23	6.50—7.10	Trace	—	63	55	Bright sunlight	No marking
		7.10—9.30	0.44	0.61	65-75	50-30		
		9.30—10.50	.13	.18	75-90	30		
		10.50—11.50	Trace	—	90-95	25		
June 14	29	1.40—3.40	Trace	—	57	72	Cloudy all day	Dry plots. Seedlings 3 in. high. No mark on wheat, oats or barley; few slight marks on rye
		3.40—6.00	0.15	0.28	58-62	74-60		
		6.00—8.00	.49	.66	63-71	50-45		
		8.00—10.00	.26	.29	71	45-65		
		10.00—14.20	.16	.22	71-75	65-48		
		14.20—15.50	.26	.30	76-74	45		
June 15	30	15.50—22.00	.45	.67	74-70	45-61	Cloudy all day 0.36 in. rain	Irrigated plots 12 by 12 plots individual barley, height 12 in., slight tip marks on 17.4% plants. On other plots planted thickly 75% of rye marked, and a few tips on wheat. No marks on oats
		22.00—1.30	.18	.28	70-68	68		
		1.30—3.15	.38	.43	66	68-82		
		3.15—5.00	.27	.32	66-64	78-82		
		5.00—6.45	.14	—	64-65	82-79		
		6.45—10.00	.17	.28	65-71	79-60		
June 16	31	10.00—12.40	.35	.45	71	60-45	Cloudy all day 0.31 in. rain	Stroh recorder shut down. Marble records indicated a fumigation. These concentrations were doubled and applied at Summerland
		12.40—18.40	.11	.20	71-74	45-57		
		18.40—24.00	.25	.43	74-68	57-79		
		0.00—3.20	.05	—	68-64	79-80		
June 13	28	6.20—7.00	0.08	—	65-68	40-35	Cloudy all day	Markings on irrigated rye found on 50% of plants. Few very small white tips on barley plot
		7.00—7.40	.30	0.36	68-70	35		
		7.40—9.00	.54	.62	70-74	33		
		9.00—10.00	.26	.32	75	30		
June 10	25	20.00—24.00	0.06	0.12	57-51	73-78	Clear	
June 11	26	0.00—2.00	.05	.07	50	78-82		
		2.00—4.40	.19	.25	49	82-64		
		4.40—6.40	.06	.11	49-56	64-50		
		6.40—7.20	.48	.60	59	50-45		
		7.20—9.40	.30	.43	59-70	45-32		
		9.40—11.00	.05	.07	70-75	30		

BARLEY UNDER FIELD AND EXPERIMENTAL CONDITIONS

Plot B-5, Summerland

Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
June 14	25	9.20—10.00 10.00—12.00 12.00—12.35	0.13 .52 .14	— 0.71 .16	88 79-74 74	43 48-60 55	Bright sunlight, rapidly clouding over after 10.00	No marking
June 17	28	8.15—10.20 10.20—12.00 12.00—15.20 15.20—17.40 17.40—21.00 21.00—24.00	0.23 .50 .25 .16 .30 .57	0.34 .64 .31 — .32 .66	66-69 69 69-73 73 60 58	71 68 72-65 65-61 61-68 —	Very dull, cloudy. 4,300 units	First SO ₂ markings noticed on June 19. Injury was slight, about 25% of plants had 5th, 6th and 7th leaves marked about 1/4 in. Less than 1% total leaf area was affected. The plants in cabinets were 20 in. in height, in 7th leaf stage and had an average of 6 tillers per plant. Outside control plots were about 2 in. shorter
June 18	29	0.00— 3.00 3.00— 6.00 6.00— 8.40 8.40—11.40 11.40—16.00 16.00—18.00 18.00—24.00	.36 .32 .40 .23 .17 .31 .10	.42 .36 .44 .26 .20 .36 .16	58-54 54-58 58-65 65-77 72-75 75-60 60-53	90 90-65 65-61 61-56 65-54 57-86 97	Occasional clouds, 5,000-6,000 units	
June 19	30	0.00— 4.00 4.00— 8.00	.06 .11	— .17	53 53-63	96 96-75	Partly cloudy	
June 21	32	9.20— 9.40 9.40—11.00 11.00—12.00 12.00—12.40	0.18 .35 .67 .22	— 0.47 .76 .31	73 73-83 83-79 77	50 58-50 52 55	Cloudy, 5,500 units	The heads had begun to form, though still enclosed by two or three leaves and the internodes were rapidly elongating, increasing the height of the plants
June 21 June 22	32 33	19.30—24.00 0.00— 4.10 4.10— 7.50 7.50— 9.50 9.50—10.30	0.11 .12 .17 .47 .21	0.14 — .23 .64 .28	56-53 53-50 50-53 56-70 70-73	95-97 97-90 90-80 75-62 58	Cloudy, 5,000 units	Fresh SO ₂ injury appeared June 22. Markings confined to tips of younger leaves on about 50% of plants. Fumigated plants slightly chlorotic

TABLE XII—COMPARATIVE SUSCEPTIBILITY OF

Stroh Farm								
Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
June 11	26	21.20—23.00	0.09	0.14	62-57	60-67	Bright sunlight	No markings
June 12	27	23.00— 0.20	.28	.37	56	67-75		
		0.20— 3.40	.13	.18	56-47	75-78		
		3.40— 6.00	.05	—	47-59	78-45		
		6.00— 7.40	.10	.15	59-66	45-30		
		7.40— 8.40	.40	.44	66-70	30-27		
		8.40—10.20	.14	.24	70-75	27-20		
June 20	35	7.00— 7.40	Trace	—	60	60	Cloudy, 60% of daytime, 0.04 in. rain	Dry plots Seedlings 5 in. in height. Few barley, 20% rye and no wheat or oat plants marked Irrigated plots Markings— oats 0%, barley 9.5%, rye 47.5% wheat 0%
		7.40— 8.20	0.19	0.24	63	60		
		8.20—10.00	.43	.47	63-70	60-46		
		10.00—10.40	.25	.28	70-75	46-40		
		10.40—11.20	.06	—	76	40		
June 20	35	21.40—23.20	0.15	0.20	55	85-93	Cloudy, 0.02 in. rain	Irrigated plots 12 by 12 plots barley, 93% of plants show tip marks. Thick plots, rye-90% of plants show tip marks. Oats and wheat none Individual plants marked Oats, 0% barley, 60%, rye, 48.5%, wheat, 0%
June 21	36	23.20— 3.00	.06	—	55-51	93-90		
		3.00— 6.40	.12	.15	51-60	90-70		
		6.40— 8.30	.16	.18	60-66	70-55		
		8.30— 9.25	.29	.36	66-70	55-46		
		9.25—11.15	.16	.21	70-75	46-60		

BARLEY UNDER FIELD AND EXPERIMENTAL CONDITIONS

Plot B-5, Summerland								
Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
June 23	34	21.40—24.00	0.18	0.22	54	85-70	Bright sunlight	Chlorosis is not evident on any of the control plots. B-5 plot is not as thrifty as its control. Plants have not stooled out as well as the cabinet control plants
June 24	35	0.00— 4.00	.20	.22	54-48	70-85		
		4.00— 6.00	.20	—	48-54	85-62		
		6.00— 8.00	.24	.26	54-60	62-48		
		8.00— 9.00	.25	.27	60-62	48-37		
		9.00—10.00	.42	.50	62-80	40		
June 27	38	8.20— 8.35	0.34	—	65	57	Up to 9.30, 5,200 units. 9.30-11.30, 9,000 units	Slight, fresh symptoms of injury appeared on June 28, 75% of tips now marked. Chlorosis more pronounced
		8.35— 9.55	.56	0.62	71	56		
		9.55—10.35	.25	.27	72-79	56-46		
		10.35—11.30	.11	.14	80	46-42		
June 27	38	23.45— 0.20	0.08	—	50	95	Cloudy 50% of time	
June 28	39	0.20— 1.40	.21	0.27	50-46	95-90		
		1.40— 5.00	.27	.30	45	90-85		
		5.00— 7.00	.31	.37	45-53	85-70		
		7.00— 9.40	.43	.57	53-60	70-40		
		9.40—12.00	.19	.33	60-66	35		

TABLE XII—COMPARATIVE SUSCEPTIBILITY OF

Stroh Farm								
Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
June 23	38	0.00— 2.00	0.05	0.11	50	95-98	Cloudy 50% of time, 0.14 in. rain	On 12 by 12 barley plot difficult to tell if fresh injury present as nearly all tips already marked.
		2.00— 5.00	.11	.18	49	98-85		
		5.00— 8.00	.36	.54	50-60	85-60		
		8.00—10.00	.21	.27	60-65	60-50		
		10.00—12.00	.05	—	65	50-80		
June 24	39	23.00— 0.50	.05	—	56	73	Cloudy all day	The percentage of marked plants in the thinned rows did not increase after the fumigation of June 23-25, but some marking occurred on the dry and irrigated rye plots, and on the seedling alfalfa plot, as well as the 1930 alfalfa plot
June 25	40	0.50— 2.10	.17	.20	56	77		
		2.10— 3.10	.30	—	55	80	Cloudy, 0.07 in. rain	
		3.10— 5.10	.19	.24	55	83		
		5.10— 6.10	.39	.42	56	77		
		6.10— 9.50	.22	.38	63	77-67		
		9.50—13.00	.12	.16	63-70	67-60		
		13.00—16.40	.11	.16	70-67	60-76		
		16.40—18.40	.27	.30	67-60	76-95		
		18.40—20.00	.45	.51	—	—		
		20.00—21.00	.72	.79	60	95		
		21.00—23.40	.49	.58	59	100		
June 26	41	23.40— 0.20	0.20	0.23	—	—	Rain	
		0.20— 8.00	.08	.14	59-65	100-82		
June 29	44	8.00— 9.40	0.15	0.18	54-55	80	Cloudy all day 0.15 in. rain.	No marking
		9.40—10.40	.19	—	55	80		
		10.40—12.00	.08	.14	55-60	80-60		

BARLEY UNDER FIELD AND EXPERIMENTAL CONDITIONS

Plot B-5, Summerland								
Date	Age of plant from date of seeding, in days	Sulphur dioxide treatment			Temp., °F.	Humidity, %	Character of day	Remarks
		Time	Average conc., p.p.m.	Maximum conc., p.p.m.				
June 29	40	8.15—8.35	0.21	—	60	68	Rain	Fresh SO ₂ injury appeared on June 29. Involving now about 90% of plants in B-5.
		8.35—11.15	.48	0.56	60-62	78-55	9.15-10.	
		11.15—14.35	.21	.25	62-82	50	0.05 in.,	
		14.35—16.40	.15	.22	82-58) 58-64)	45-77 77-67	bright sunlight 10-13.30, rain	
July 1	42	0.00—0.20	.05	—	50	55	14.30-	Further SO ₂ injury developed as a result of fumigation of July 1 and 2. Nearly every plant now affected in some degree. Chlorosis more pronounced on fumigated plot than control
		0.20—3.20	.47	.54	50-46	55-70	15.30.	
		3.20—6.00	.43	.52	46-55	70-60	.04 in.	
		6.00—9.20	.28	.31	55-80	60-45	Bright sunlight, 12.000	
		9.20—12.40	.14	.19	82-96	45-31	units.	
		12.40—15.10	.12	.16	96-70	31-54	Occasional clouds in afternoon.	
		15.10—16.30	.67	.79	70-94	54-31		
		16.30—19.10	.16	.27	94-70	31-40		
		19.10—24.00	.12	.26	70-60	40-70		
July 2	43	0.00—8.00	0.03	—	60-52-60	90-60		Chlorosis quite pronounced.
July 7	48	9.40—11.40	0.13	0.16	90-92	40	Bright sunlight, 12,000 units	No new marking
		11.40—13.20	.19	.22	90-92	38		

Total of 213 hr. 50 min. gas. Average conc. over whole period—0.27 p.p.m.

CHAPTER XII

THE STOMATAL BEHAVIOR OF FUMIGATED ALFALFA

BY MORRIS KATZ AND G. A. LEDINGHAM

Introduction

Since stomata are known to play a major role in the gaseous exchange in plants, it seems reasonable to assume that their behavior must be a factor of some importance in relation to the problem of sulphur dioxide injury to vegetation. References to stomata in the literature concerning the action of sulphur dioxide on plants either deal with their function as the path along which the gas goes into the leaves (2), or postulate their probable relationship to the decreased susceptibility of plants growing in the dark or suffering from lack of water (6). So far as the authors are aware, there is no information available concerning the specific action on stomatal behavior of sulphur dioxide at various concentrations of known duration. Studies of this nature should throw some light on the problem of sulphur dioxide toxicity and the various factors which influence it.

The present studies were made at the Experimental Station, Summerland, B.C., during the course of experimental fumigations of alfalfa on field plots in 1935 and 1936. Unfortunately the time and opportunity for a detailed study on several plant species with different stomatal reactions were not available, and alfalfa was the only species investigated. The answer to many questions must, therefore, await further experimentation particularly in the case of those plants for which day closure and night opening is the normal sequence of events. In this work we wished to derive information on the following questions:

- (1) What concentration of sulphur dioxide will alfalfa tolerate without change in normal stomatal behavior?
- (2) Is it possible for sulphur dioxide gas to bring about stomatal closure without visible indications of injury to the leaves?
- (3) Are the stomata open or closed when acute or chlorotic injury appears on a leaf?
- (4) Is the reduction of assimilation, which the studies on carbon dioxide exchange in the presence of high concentrations of sulphur dioxide revealed, due to the effect of gas on the stomata?

In addition to the phases of the problem which relate directly to the presence of sulphur dioxide, some information was obtained on the normal stomatal behavior of unfumigated plants. Throughout the work continuous records of humidity, temperature and light were taken. Soil moistures were determined when it seemed advisable, and in some instances a continuous record of the carbon dioxide assimilation and respiration was also available for correlation with the stomatal measurements.

Description of Methods

Direct Microscopic Measurements

Throughout the course of this investigation numerous observations and measurements of stomata were taken on living leaves with a microscope and ocular micrometer. The most satisfactory combination of lenses was found to be a 20 low power objective and a 15 ocular. At this magnification one division on the ocular micrometer scale was equivalent to 3.4 microns. As the maximum stomatal diameter, with rare exceptions, was found to cover three divisions on the micrometer, 10.2 microns was thus regarded as indicative of full stomatal aperture. Practice in visual examination of stomata made it possible to classify the different stages of opening into various classes with an accuracy almost equal to that of actual measurements with the micrometer. Table I gives the stomatal classes and their approximate diameter in microns. Without the employment of higher magnifications, which would be difficult to use in the field, it is doubtful whether a finer subdivision would have been any more accurate. The openings shown in Table I are those found to be present on a day of high light intensity, under moderate temperatures, with relatively high humidity.

TABLE I
NORMAL DAILY MARCH OF STOMATAL MOVEMENT ON ALFALFA
AT SUMMERLAND, B.C.

Time	Stomatal class, % of full opening	Approx. diameter in microns
5.00 a.m. — 6.00 a.m. -----	0 — 25	—
6.00 a.m. — 7.30 a.m. -----	25 — 50	3.4
7.30 a.m. — 9.30 a.m. -----	50 — 75	6.8
9.30 a.m. — 3.30 p.m. -----	75 — 100	10.2
3.30 p.m. — 4.30 p.m. -----	75 — 50	6.8
4.30 p.m. — 5.30 p.m. -----	50 — 25	3.4
5.30 p.m. — 7.00 p.m. -----	25 — 0	—
7.00 p.m. — 4.30 a.m. -----	closed	—

Our experience in regard to the variation in the behavior of individual stomata on a leaf, and on the different sides of a leaf, was very similar to that reported by Loftfield in his work on alfalfa (5). Opening was not always the same on both upper and lower epidermis, although the difference was seldom great enough to change the picture significantly. Similarly, on one leaf, stomata were occasionally functionless, or much more widely open than others, but these differences were negligible provided that a sufficient number of observations were made. A much greater source of variation was found to be due to differences in stomatal aperture from leaf to leaf, depending mainly on age, the position on the plant, and the degree of maturity of the plant. In general, on the older leaves near the base of the plant, stomata open later in the morning and close earlier in the afternoon, compared with fully expanded upper leaves.

The stomata on young unfolding leaves are less active and more variable in size than those on mature leaves. All the studies on the effect of sulphur dioxide on stomatal movement were, therefore, made on upper fully expanded leaves.

While direct microscopic measurements proved valuable for general studies on stomata, it soon became clear that it would not be possible to trace the effect of sulphur dioxide on leaves by this method with any degree of precision. Further studies were, therefore, undertaken using Lloyd's (4) absolute-alcohol-strip method and automatic porometers based on the method described by Knight (3). It was found that the automatic porometer was most useful where long continued fumigations with low concentrations of sulphur dioxide were in progress. The absolute-alcohol-strip method was, therefore, used mainly for the higher concentrations of sulphur dioxide.

Automatic Porometer

The porometer constructed and used in this work is shown in Fig. 1. It consists essentially of two glass tubes, the inner one containing a platinum wire reaching nearly to the bottom of the tube and so constructed that it may be raised or lowered inside the tube. The outer glass tube contains a platinum contact sealed into the bottom and covered with a layer of mercury. This tube is about one-third filled with distilled water. The platinum wire in the inner tube is so adjusted that it touches the mercury surface. A side arm near the top of the inner tube leads to a rubber connection which is attached to the leaf. Another side arm on the outer tube is connected to a source of suction which must be equalized by the use of a surge-tank. In operation a small rubber tube, the end of which had been heated to render it sticky, was attached to a leaf and the suction then adjusted to draw air through the leaf when the stomata were open. The air entered the porometer in a series of bubbles, the rate of bubbling depending on the extent of the stomatal aperture and the number of stomata on the surface of the leaf enclosed by the rubber tube. When the stomata were closed, practically no air was drawn through the leaf, or the rate of bubbling was very slow. Each bubble of air in passing through the inner to the outer tube agitated the mercury surface, and in so doing broke an electrical circuit. This interruption was transmitted to a relay which moved the pen in a holder attached to it. The relay was mounted on one side of the recording galvanometer used for recording carbon dioxide readings, in such a manner that marks corresponding to each movement of the relay pen were obtained on the paper. Since the recorder paper travelled at a constant speed it was possible by this means to obtain a continuous record of stomatal movement. The instrument was calibrated by comparison with direct microscopic observations on the stomatal aperture, so that a definite number of marks on the paper per unit length corresponded to a definite average width of stomatal aperture in microns. On occasion two porometers of identical construction were employed in order that simultaneous readings might be obtained from both the control and the

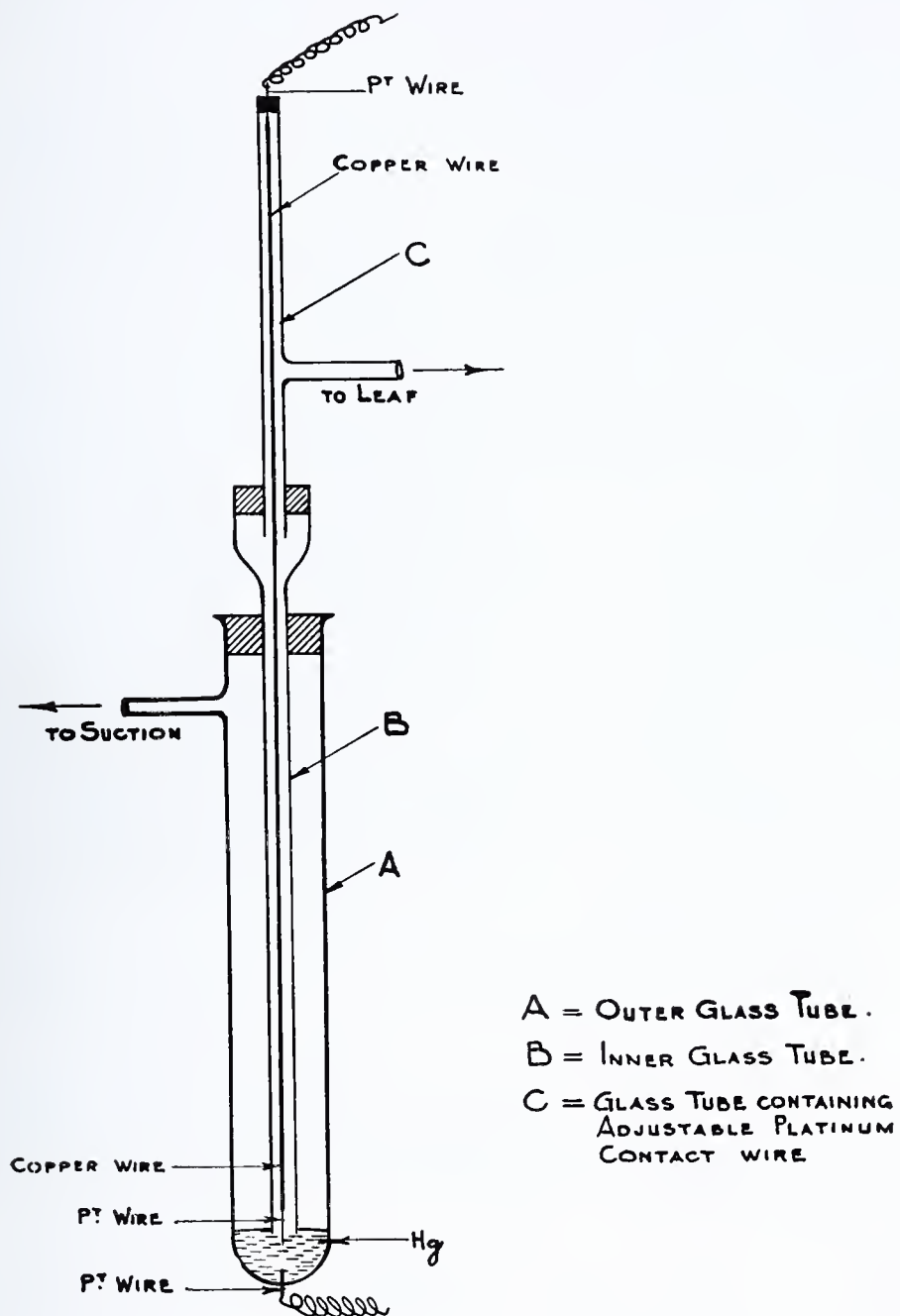


FIG. 1. Automatic porometer

sulphur dioxide treated plots. The porometer was usually used in connection with experiments on carbon dioxide assimilation. It has, therefore, been possible to correlate stomatal opening in some cases with the amount of carbon dioxide assimilated per hour.

Absolute-alcohol-Strip Measurements

In all stomatal measurements determined by this method the following procedure was adopted. Epidermal strips were taken from alfalfa leaves in both control and fumigated cabinets at the same time, before, during or after the various sulphur dioxide treatments. The strips were immediately plunged into absolute alcohol. Several strips were always taken for each test from fully expanded upper leaves in order that individual leaf variations might be eliminated. A separate vial was used for upper and lower epidermal strips. As soon as possible after collection the strips were mounted in absolute alcohol on glass slides, and microscopic observations were taken in the laboratory. In order to make comparisons it was necessary to adopt some uniform method of classifying size of stomatal aperture for each of the different collections. To make measurements of hundreds of stomata with the ocular micrometer would necessarily have entailed a great deal of work, and it was felt that an average diameter for each collection would not show the trend of stomatal movement as clearly as a system of classes with final results expressed as an index factor. From a consideration of the principles of gaseous diffusion, as laid down by Brown and Escombe (1) for small apertures, it was apparent that openings less than 50% of maximum should be weighted more heavily than those that were greater, if a true index factor was to be obtained. It was, therefore, decided to classify the stomata in respect of size of opening into but four classes, viz.:

1. Stomata entirely closed;
2. Stomata not more than 25% open;
3. Stomata open from 25 to 50%;
4. Stomata open from 50 to 100%.

In practice, since measurements were not taken with a micrometer, it was possible to segregate rapidly from 100 to 150 stomata for each collection into these classes. With an ocular micrometer present for comparison when necessary, the error involved would not be greater than reading the scale to fractions of one division.

The average index factor was determined by multiplying the number of stomata in a class by the class number and dividing the sum of these products by the total number of stomata.

Experimental Results

During the course of this investigation approximately 18 different concentrations of sulphur dioxide were tested with respect to their effect on stomatal

behavior. For clarity of presentation these have arbitrarily been divided into three classes, viz.: high, medium and low concentrations. The first includes concentrations between 5.80 and 1.00 p.p.m., the second from 0.89 to 0.40 p.p.m., and the lowest from 0.29 to 0.10 p.p.m. In addition to these experiments, some data which might be discussed here, were available from stained leaf sections used in connection with morphological studies. In the case of Plot E-12, which was treated with 3.00 p.p.m. of sulphur dioxide for 40 min., stomata were closed on the injured parts of the leaf at 9.15 a.m., 35 min. after the start of the fumigation (Fig. 118, Plate I), and were nearly closed on leaves which had not been injured (Fig. 119, Plate I). The stomata in leaves from the control plot were nearly wide open at the same time (Fig. 120, Plate I). On stained sections of leaves taken from Plot E-12, 10 days later, the stomata were wide open, except where the leaf tissue had been killed. Photomicrographs are also shown in Plate I of stained leaf sections from Plot C-12, control, and Plot C-11, treated with 0.10 p.p.m. sulphur dioxide for 504 hr. In a collection made at 1.00 p.m. on the final day of the experiment the stomata from both plots were entirely normal in appearance. Stomata on green fully expanded upper leaves from the treated plot are shown in Fig. 113, and from the control plot in Fig. 114, Plate I. Chlorotic lower leaves with open stomata are shown for the control plot in Fig. 115, and the fumigated plot in Figs. 116 and 117. Microscopic examination of the guard cells in these leaves showed them to be quite normal in all specimens examined.

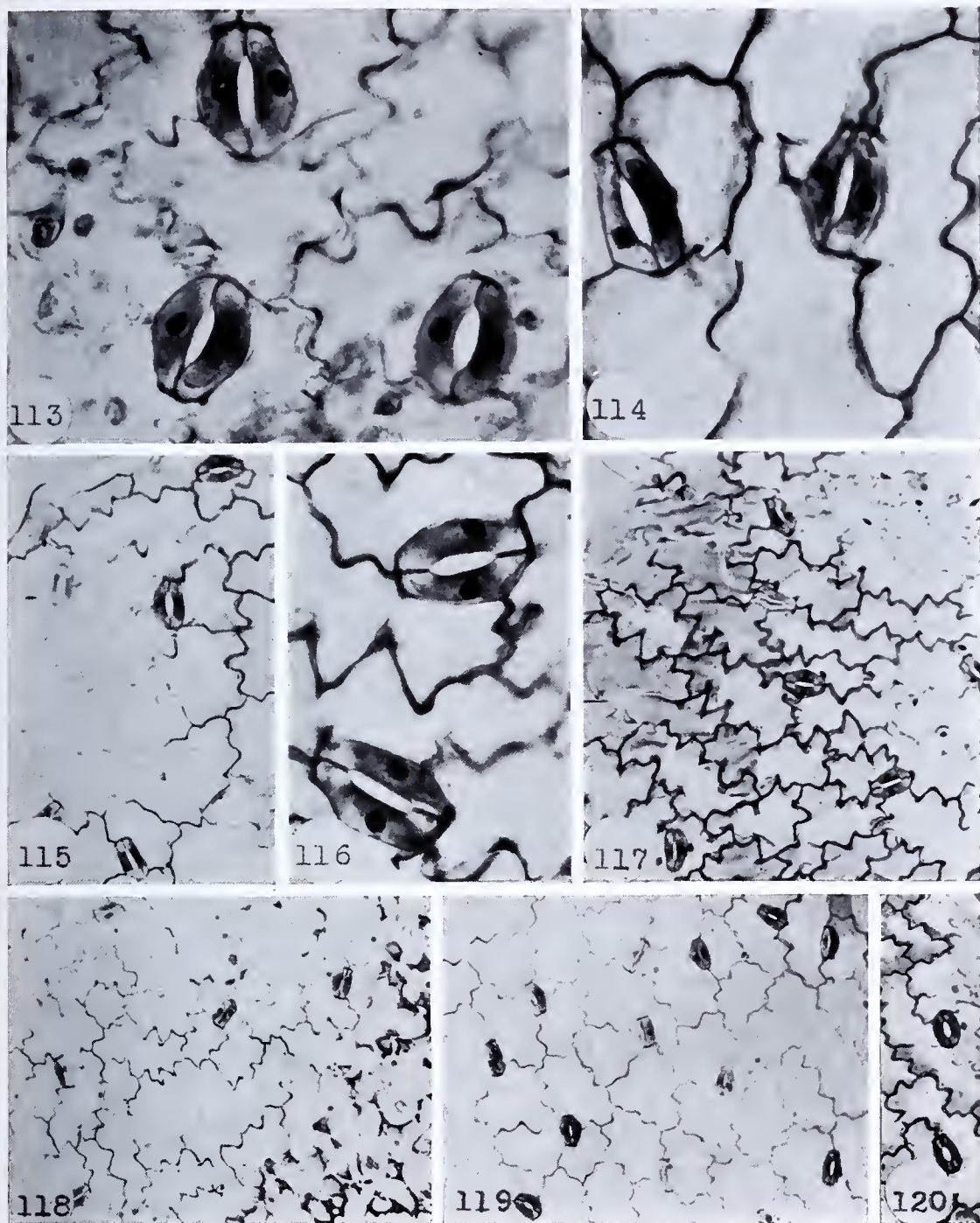
The photomicrographs on Plate II were made from epidermal strips preserved in absolute alcohol. In a four hour treatment with 0.57 p.p.m. sulphur dioxide, from 8.45 a.m. to 12.45 p.m., the stomata remained open as did the control. (Plate II, Figs. 121 and 124 from treated Plot C-16; Figs. 122 and 123 from control Plot C-15.) However, during exposure to a concentration of 2.96 p.p.m. for four hours (8.00 a.m. to 12.00 noon), strips taken at 11.30 a.m. show that the stomata were closed even on parts of the leaves where no markings were present. (Plate II, Fig. 125, Plot D-7, treated; Fig. 126, Plot C-7, control).

Treatment with High Concentrations of Sulphur Dioxide

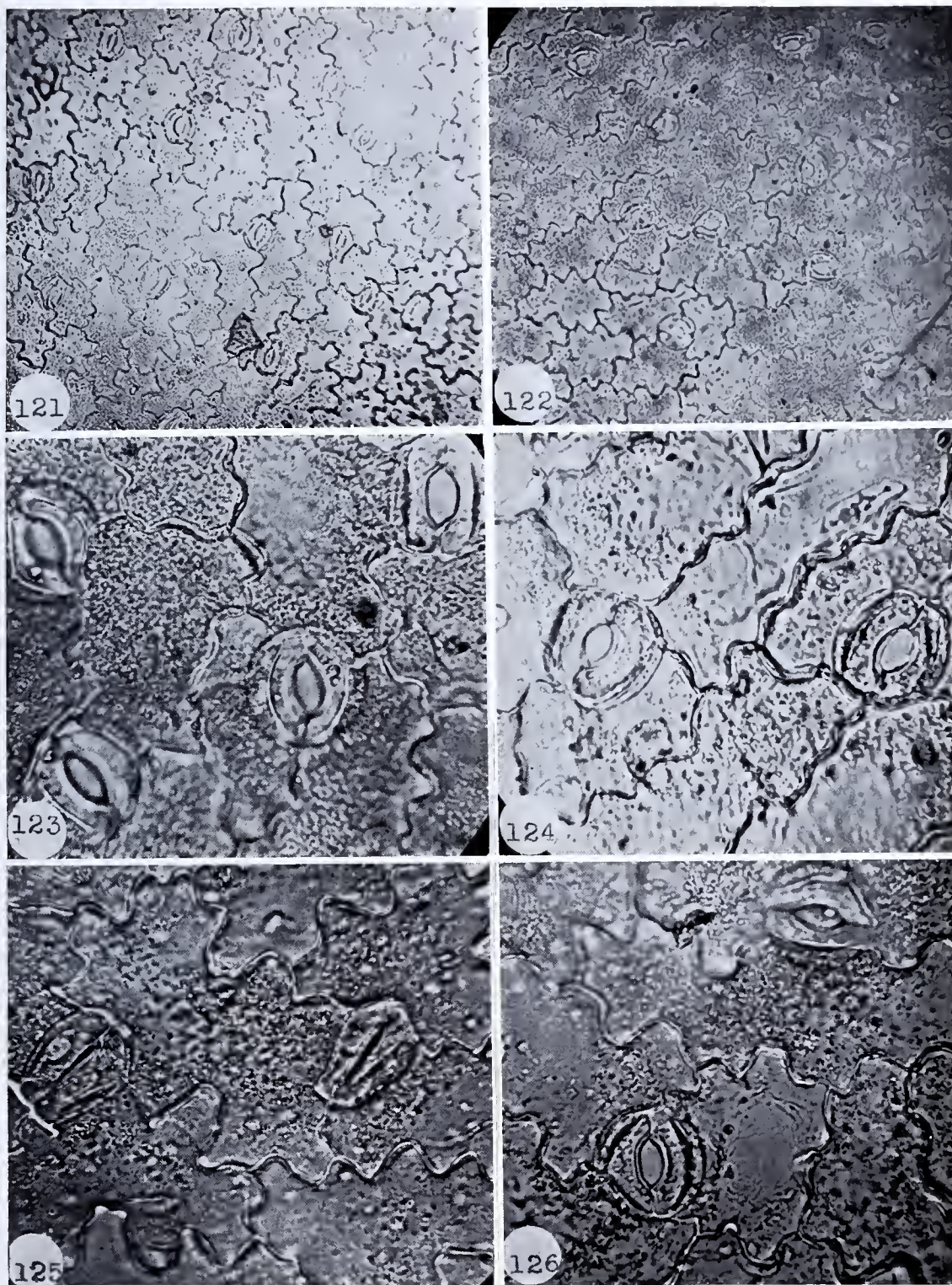
All the measurements in this series were made by means of the absolute-alcohol-strip method. In all about eight different sulphur dioxide concentrations, ranging from 5.80 p.p.m. down to 0.97 p.p.m., were tested. In some instances only short treatments were given, but usually plots were exposed to the gas for four hours. Sometimes there were two or more intermittent fumigations. The action of sulphur dioxide at a concentration of 5.0 p.p.m. may be observed from Table II. The gas was applied in two 15-min. treatments during the same morning on July 22, 1936. This was a day of high light intensity, as indicated by the light records, and temperature was moderately high. Soil moisture was quite high on the treated plot, but on the control it was considerably lower although not near the wilting point. The humidity of the air,

on the other hand, was lower in the treated cabinet than in the control cabinet. Before fumigation the stomatal index factors for both plots were quite comparable, the control being 2.89 and the fumigated 2.84. The stomatal distribution in the different classes was quite comparable in both cases. Following the fumigation, which took place at 9.25 a.m., it was evident that in the control the stomatal opening was still increasing as the index was now 2.92 and more stomata were present in Class 4 than previously. For the treated plot the stomatal index decreased to 2.33 and the number of stomata in Class 4 was less than half the number present earlier. During the treatment 12% of the stomata had closed, whereas before fumigation there were scarcely any stomata in this class. Another series of measurements taken approximately an hour after the close of the fumigation indicated that in the control the stomata were still opening, the index being 3.11, with 22.7% of the stomata in Class 4, and none in Class 1. In D-11, the treated plot, the index was lower than it was previously, with 17% of the stomata closed, and only about 7% in Class 4. Following a further 15-min. sulphur dioxide treatment with 5.80 p.p.m., shortly after 11 a.m., a further decrease in stomatal opening occurred in the treated plot. The index was now 1.95 with 32.3% of the stomata closed. In the control, on the other hand, there were no stomata closed, and 26.7% were in Class 4, the index now being 3.05. A final collection taken at 1.30 p.m. (two hours after the close of the fumigation) indicated that in the control the stomata had begun to close slightly, the index dropping to 2.76, with only 12.6% in Class 4, and a few stomata fully closed. In the treated plot there were 40.9% of the stomata closed, and very few wide open. The index factor was 1.69.

Data on stomatal behavior as affected by concentrations of sulphur dioxide of approximately 3.00 p.p.m. are given in Table III. Plot D-7 was treated with 2.96 p.p.m. for four hours during the morning. Observations on the stomata were taken on leaves on which injury was visible, and on others on which there were no indications of injury from the treatment. The morning was bright and the temperatures did not exceed 87°F. Soil moisture and humidity were very much the same in both cabinets. At 7.30 a.m. the stomatal index factors for both treated and control plots were similar, although a higher percentage of the stomata were wide open in the former. At 11.30 a.m., after three and one-half hours of fumigation, the index for the control was higher than it had been at 7.30 a.m., and the number of stomata in Class 4 had greatly increased. Leaves from the treated plot, where no visible injury was present, had a very low stomatal index of 1.42; 58.5% of the stomata being closed, with none present in Classes 3 and 4. There was practically no difference, irrespective of whether or not visible injury had occurred. At 3.30 p.m. on the same day the stomatal index for the control was slightly lower than it had been at 11.30 a.m. In the treated plot the index factor had increased from 1.41 to 1.67, and the percentage of stomata fully closed was now 32.9. However, none had recovered sufficiently to be included in Classes 3 and 4.



Photomicrographs of stomata from stained sections of alfalfa leaves. FIG. 113. Stomata in upper green leaves of Plot C-11 at the close of a 504 hr. fumigation, September 6, 1935, 1.00 p.m. Leaf treated with B.C. fixative. Magnification $\times 700$. FIG. 114. Stomata from control Plot C-12 taken at the same time as those in FIG. 113, and treated similarly. Magnification $\times 700$. FIG. 115. Stomata on lower chlorotic leaves of Plot C-12 (control). Magnification $\times 233$. FIG. 116. Stomata on lower chlorotic leaves Plot C-11 at close of 504 hr. fumigation on September 6. Magnification $\times 700$. FIG. 117. Stomata on lower chlorotic leaves of Plot C-11 at close of experiment, September 6. Magnification $\times 233$. FIG. 118. Section through leaf from Plot E-12, treated with 3.0 p.p.m. for 40 min. on September 4. Section shows injured cells and stomata closed at 9.15 a.m. Magnification $\times 200$. FIG. 119. Stomata from leaves of Plot E-12, non-injured part of leaf showing stomata beginning to open at 9.15 a.m. Magnification $\times 200$. FIG. 120. Stomata from leaves of Plot E-11 (control to E-12) taken at the same time as FIGS. 118 and 119, showing stomata wide open at 9.15 a.m. Magnification $\times 200$.



Views of stomata in epidermal strips in absolute alcohol. FIG. 121. Stomata on upper epidermis of leaf from Plot C-16, immediately after treatment for four hours at 0.57 p.p.m. sulphur dioxide. 1.00 p.m. Magnification $\times 233$. FIG. 122. Stomata on upper epidermis of Plot C-15, control to Plot C-16, taken at same time as above. Magnification $\times 233$. FIG. 123. Stomata on upper epidermis of Plot C-15, control to Plot C-16. Magnification $\times 700$. FIG. 124. Stomata on upper epidermis of Plot C-16. Same treatment as in FIG. 121. Magnification $\times 700$. FIG. 125. Stomata on lower epidermis of leaf from Plot D-7, treated with 2.96 p.p.m. sulphur dioxide for four hours. Taken at 11.30 a.m. at close of treatment. Stomata closed. Magnification $\times 700$. FIG. 126. Stomata on lower epidermis of leaf from Plot C-7, control to Plot D-7, taken 11.30 a.m. Stomata open. Magnification $\times 700$.

Data showing the effect of sulphur dioxide at a concentration of 1.47 p.p.m. on the stomata of alfalfa are presented in Table IV. This treatment covered a period of four hours on the morning of July 17, 1936. The light record indicates fairly high intensity, and temperatures ranged from 70°F. in the morning to over 90°F. at noon. The soil moisture and humidity were quite comparable in both control and fumigation cabinets. The index factor at 7.30 a.m. for the control leaves was 2.58, and for leaves from the plot to be treated, 2.36. More stomata were present in Class 4 in the control plot D-4 than in C-4. At 11.30 a.m., three and one-half hours from the beginning of the fumigation, the control plot had changed very little from its condition at 7.30 a.m., whereas in the treated plot marked closure had taken place, the index being 1.74. By 2.45 p.m., although most of the stomata in the control were still in Classes 2 and 3, a slight increase in the index number had occurred. In the treated plot some recovery had taken place, for only 9% of the stomata were now closed, but there were still none in Class 4. The index was now 2.02. The marked recovery of the stomata after the gas was removed indicates that this effect is only temporary.

On July 16, 1936, a treatment with a slightly lower concentration than the one just described was applied to Plot D-5. The results are given in Table V. The light was considerably higher during this day but temperatures were not so extreme, and humidity and soil moisture conditions were very similar on both control and treated plots. At 7.30 a.m. the stomatal index and the distribution of the stomata in the various classes were quite similar on both treated and control plots. At 11.30 a.m., after three and one-half hours' treatment with 1.27 p.p.m. of sulphur dioxide, the stomatal index for the treated plot was 1.47, and 54% of the stomata were closed. Practically all were in Classes 1 and 2. The control, on the other hand, had not changed significantly from the condition found at 7.30 a.m. In the afternoon further observations taken at 3.30 p.m. indicated some recovery; 19% of the stomata on leaves from the treated plot were still closed, however, and very few were in Classes 3 and 4. The index was now 1.83, compared with 2.44 for the control.

The results of a gas treatment with a still lower concentration, 1.04 p.p.m., applied for four hours to Plot D-17, on July 15, 1936, are shown in Table VI. Observations from strips taken at 7.30 a.m. from both plots showed quite comparable index factors, 2.57 for the control and 2.45 for the plot to be treated. No stomata in either plot were closed. However, three and one-half hours after the start of the fumigation the index factor for the treated plot was 1.67, 34.2% of the stomata were closed, and the remainder were nearly all in Class 2. In the control plot at the same time 3.5% of the stomata were closed, but 19.1% were now in Class 4, as compared with 2.3% earlier in the morning. Further observations taken at 3.30 p.m. indicated considerable recovery in the treated plot. The index was now 2.20, compared with 2.38 for the control. There

were just as many stomata in Class 4 in the treated plot as in the control, and in the former 21% were now in Class 3.

On August 11, 1936, another sulphur dioxide experiment at a concentration of 1.0 p.p.m. was carried out to determine the effect of a longer period of treatment, and also that of variable light intensity on the stomata. Two plots, G-6 and G-8, received identical sulphur dioxide treatment (see Table VII). One of these, G-8, was covered with canvas so that it received only 200 ft-candles of light as compared with intensities ranging from 3,200 to 7,600 ft-candles on G-6. Moderately high temperatures prevailed after 10 a.m. during this experiment. The humidities in the different cabinets were very similar. There was a slight difference in soil moisture but this was not great enough to have an appreciable effect on plant growth. At 8 a.m., before the gas treatment was started, the index factor for the control plot G-9 was 2.63; for G-6 it was 2.57, and for G-8, 2.53. The distribution of the stomata in the various classes was quite comparable for all three plots. Sulphur dioxide treatment of both plots was started at 8.15 a.m. The average concentration for a period of seven hours was 1.0 p.p.m. for G-6 and 0.97 p.p.m. for G-8. Stomatal measurements were made at 10 a.m. on leaves from the control and treated plots. It is apparent from the index factors that sulphur dioxide had not a very marked effect on the stomata during the initial one and three-quarter hours of treatment. In the control plot the index factor was 2.64, with 13.6% of the stomata in Class 4, and none closed. In the case of Plot G-6 the index factor was 2.44, and 7.8% of the stomata were in Class 4. None of the stomata were closed at this time. It is apparent that the low light intensity on Plot G-8 as well as the presence of sulphur dioxide had an effect on the stomata. The index here was 2.21, 9.9% of the stomata were closed, and only a few were present in Class 4. By 1.15 p.m. the sulphur dioxide treatment had caused very marked closure in both treated plots. In comparison with the control where the index was 2.61, it was now 1.52 for Plot G-6 and 1.16 for Plot G-8. In the two treated plots the distribution of the stomata had changed greatly; none were present in Classes 3 and 4 on either plot. In Plot G-6 48% were closed, and in Plot G-8, 84.8%. In the control only 2.1% of the stomata were closed. The greater closure in Plot G-8 is no doubt due to the low light intensity. Even without sulphur dioxide treatment the stomata would probably have closed earlier in this plot. Measurements of epidermal strips taken at 3.15 p.m. at the time the sulphur dioxide was removed from the cabinets indicated that the period of greatest effect on the stomata had been reached at 1.15 p.m. The index for the control was now 3.0, and 29% of the stomata were in Class 4. It is apparent that some opening had taken place since noon. On Plot G-6, with high light intensity, the index was 1.97, and the presence of 22% of the stomata in Class 3, and 3.5% in Class 4, compared with none in these classes earlier in the afternoon, indicated that considerable opening, rather than closure, had been taking place. On Plot G-8, with low light intensity, there had been slight recovery; approximately half as many stomata

were completely closed as in the previous collection, but none were present in Classes 3 and 4 at this time.

Treatment with Medium Sulphur Dioxide Concentrations

Various concentrations of sulphur dioxide, between 1.0 and 0.40 p.p.m., are included in this class. Experiments were made with the following concentrations: 0.89, 0.84, 0.76, 0.57, 0.44, and 0.40 p.p.m. Two plots, H-5 and G-11 were similarly treated from 8.30 a.m., August 12, until 4.30 a.m., August 13, with 0.89 and 0.84 p.p.m. of sulphur dioxide. The cabinet over Plot H-5 was exposed to sunlight while that over Plot G-11 was covered with canvas. G-7, like H-5, was exposed to sunlight and used as a control to both treatments. The results are given in Table VIII. No measurements were made of stomata before fumigation, but the first strips were taken at 10.30 a.m., two hours after start of the treatment. At this time the index factor for the control plot was 2.59, and most of the stomata were distributed in Classes 2 and 3. For the treated plot, H-5, the index factor was 2.53, with almost the same number of stomata in the various classes as in the control. In G-11, on the other hand, at this time, 23.5% of the stomata were closed and the index was 1.78. The disparity between these two treated plots is due to the difference in light intensity as it was 6,000 ft-candles on H-5 and only 200 on G-11. Another set of measurements was made at 4.30 p.m., August 12. For the control the index was 2.32, for H-5, 2.21, with 7.7% of the stomata closed; and for G-11 the index was 1.65, with 35.5% of the stomata closed and none in Classes 3 and 4. Here again, the difference between Plots H-5 and G-11 was due to light rather than to sulphur dioxide treatment. At 10.30 p.m., August 12, most of the stomata were closed on all the plots. At 4.30 a.m., August 13, when the stomata were just beginning to open, the index factor for the control was 1.85; for H-5, 1.75; and for Plot G-11, 1.87. It is clear from these results and the class distribution that night treatments with sulphur dioxide in the concentrations used here have little effect on the stomata. The fact that even after 20 hr. of fumigation the stomata open at the same time and to the same degree as in the control plot indicates that concentrations of this order have little effect on the stomata until injury appears on the leaves.

Sulphur dioxide treatment at a concentration of 0.76 p.p.m. for four hours during the morning (8.00 a.m. to 12 noon) on July 16, 1936, had no effect on stomatal behavior. At 7.30 a.m., before fumigation, the index factor as shown in Table IX was 2.63 for the control plot, and 2.36 for the fumigated plot. There was some lag in stomatal opening in the plot which was to be treated, as indicated by the absence of stomata in Class 4 compared with 8.9% in this class in the treated plot. At 11.30 a.m., after three and one-half hours' treatment, the stomatal index was slightly higher for the treated than for the control plot. At 3.30 p.m., three and one-half hours after fumigation had stopped, the stomatal index was 2.44 for both control and treated plots. The distribution of the stomata was practically the same in all classes.

The results of an experiment with 0.57 p.p.m. for four hours, on July 21, 1936, are given in Table X. At 8.00 a.m., before the fumigation started, the index factor was slightly higher for C-16, which was to be treated, than for the control plot C-15. After four hours' treatment the index factor was still higher for the fumigated plot.

A four hour sulphur dioxide treatment at a concentration of 0.44 p.p.m. had no effect on stomata as indicated by the results in Table XI. Before fumigation at 7.30 a.m. both the distribution of stomata in the various classes and the average index factors were very similar for control and treated plots. After three and one-half hours of fumigation there was no significant change in the stomata compared with those of the control. In fact, the index factor was slightly higher for D-13, the treated plot, and this difference was even more marked two and three-quarter hours after the gas treatment was stopped.

The longest treatment in this series was 0.40 p.p.m. for 171 hr., from 10.00 a.m. on July 9 to 1.00 p.m. on July 16, 1935. Measurements were made with the automatic porometer. At this time only one porometer was available; hence there was no comparable check on the control plot. However, this experiment gave some interesting results which are worth while describing (see Table XII). During the first four days of sulphur dioxide treatment there was no effect whatever on the movement of the stomata of the fumigated alfalfa leaves. The stomata opened regularly in the morning, attained their maximum opening soon after 9.00 a.m., or by midday, and began to close in the late afternoon, remaining closed all night. On July 13, the record indicates that the leaf stomata only attained about 65% of their maximum opening, although the light intensity was comparable to that of July 11-12, and higher than that of July 10. Similarly, on July 15 and 16 the stomata did not open fully, but July 15 was a dull day and it is possible that a part of the effect on the stomata may have been due to the low light intensity. However, the light on July 16 was excellent, and in spite of this the stomata were only partially open even though the temperature and humidity up to 1.00 p.m. were comparable to those of July 12. It would appear, therefore, that continuous treatment with 0.40 p.p.m. of sulphur dioxide had no effect whatever on stomatal movement until after an exposure of about four days. Beyond this period some effect became noticeable, the stomata attaining only about 65% of the maximum opening. It is interesting to note that this effect appeared soon after symptoms of acute injury were noted on the plot. Toward the close of this treatment the plot became very chlorotic and finally about 27% of the leaves were marked by sulphur dioxide.

Treatment with Low Concentrations of Sulphur Dioxide

Four different experiments were carried out in this series, with concentrations of sulphur dioxide from 0.29 p.p.m. to 0.12 p.p.m. The absolute-alcohol-strip method was used to obtain information on the effect of three intermittent treatments at average concentrations of 0.29 p.p.m., 0.27 p.p.m., and 0.24 p.p.m.

Another set of measurements was made by this method at the close of a 60-hr. fumigation at an average concentration of 0.168 p.p.m. Finally, automatic porometer readings were made during two long-continued treatments at 0.14 and 0.12 p.p.m. In addition, observations on the condition of the stomata were made after a 504 hr. experiment with 0.10 p.p.m.

The results of three intermittent fumigations, each of four hours' duration, at 0.29 p.p.m., 0.27 p.p.m., and 0.24 p.p.m., are presented in Table XIII. Just before the first treatment started on July 22, 1936, at 8.00 a.m. the index factor was 3.34 for A-15, the control, compared with 2.96 for B-15. After three and one-half hours of fumigation both the index factors and stomatal distribution in classes were very similar on the two plots. The following morning at 8.00 a.m. the index was again slightly higher on A-15, the control plot. Treatment for three and one-half hours with 0.27 p.p.m. did not cause any significant change in either the index factor or distribution in the classes. On the third morning the condition of the stomata in both plots was almost identical, and although after a further fumigation with 0.24 p.p.m. the index factor was slightly lower, it is doubtful whether the small change in the stomatal index can be attributed to the sulphur dioxide.

One set of stomatal measurements was taken after 0.168 p.p.m. had been applied to Plot H-11 for 60 hr., and the data are given in Table XIV. The results indicate that there has been no adverse effect on stomatal behavior, as the index for the treated leaves is 3.50 compared with 3.38 for the control.

Automatic porometer readings for Plot I-11 and its control I-10 are given in Table XV. The average concentration of sulphur dioxide was 0.14 p.p.m., applied for 196½ hr., from 11.00 a.m. July 31 to 3.20 p.m. August 2, and from 3.00 p.m. August 3, to 4.00 p.m. August 9, 1935. In addition to the porometer readings the carbon dioxide exchange was measured in both of these plots during most of the experiment. These records are available from 11.00 a.m. August 1.

The light intensity was rather low on August 1 and the stomata of the alfalfa of both plots attained only about 75% of their maximum opening. The carbon dioxide assimilation proceeded at comparable rates on both plots. On August 2 the light intensity was high and the stomata of both plots had opened fully by 11.00 a.m. On August 3 the stomatal movement of the fumigated alfalfa plot followed that of the control closely. The carbon dioxide assimilation attained a maximum of 13.9 gm. per hr. on both plots. The light intensity dropped rapidly after 11.00 a.m., and it began to rain in the afternoon. This caused the stomata to close earlier than usual, and the carbon dioxide assimilation decreased from 13.9 gm. per hr. to about 8 gm. per hr., coincident with a drop in light intensity. Soon after the rain began there was a further very pronounced reduction in the carbon dioxide assimilation. On the following days no appreciable difference was detectable in either the movement of the stomata or the rate

of carbon dioxide assimilation between the fumigated alfalfa and the control. The measurements were continued until August 10, a full day after the sulphur dioxide fumigation had been completed. There was no effect noticeable as a result of this prolonged exposure to gas. The carbon dioxide records indicated that photosynthesis began as soon as the stomata began to open and ceased when they closed. The rate of photosynthesis parallels, in a general way, the movement of the stomata.

Stomatal measurements were made with the porometer on Plot G-8, which was exposed to 0.12 p.p.m. of sulphur dioxide for nearly 234 hr. (3.20 p.m. July 19, to 8.45 a.m. July 29, 1935). Simultaneous readings were taken on the control plot and the data for both plots are given in Table XVI for the period 4.45 a.m., July 24, to 3.00 p.m. July 27. It is clear that on the days for which records are available in this experiment, the stomatal behavior was practically identical in both plots, even after sulphur dioxide had been present for 192 hr. on Plot G-8.

Further evidence of the harmless nature of very low concentrations of sulphur dioxide toward stomata was obtained in a number of long, low concentration experiments by direct microscopic observations and, as previously mentioned, from stained sections from Plot C-11 after treatment for 504 hr. at 0.10 p.p.m. Many leaves were examined from this plot and its control C-12 throughout the course of the experiment and no significant differences in stomatal behavior were ever found. It seems reasonable to conclude therefore that with these low concentrations stomata will not be affected unless actual visible injury is produced on the leaves.

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TABLE II
EFFECT OF HIGH CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF THE STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft.-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
A-15 Control	July 22 9.10 a.m.	5,800	80	70	7.4	Upper Lower Average	0 0.9 0.5	20.8 33.0 26.9	62.4 51.4 56.9	16.8 14.7 15.7	2.98 2.80 2.89
D-11 Treated	July 22 9.10 a.m. before fumigation	5,800	85	53	12.1	Upper Lower Average	0 0.8 0.4	39.7 24.2 31.9	46.3 54.7 50.5	14.0 20.3 17.2	2.74 2.94 2.84
<i>5.00 p.p.m. for ¼ hr. (9.25-9.40 a.m.) first sulphur dioxide treatment</i>											
A-15 Control	July 22 9.55 a.m.	7,200	84	69	7.4	Upper Lower Average	0.8 0.7 0.8	33.3 21.8 27.5	55.8 45.7 50.7	10.1 31.8 21.0	2.75 3.09 2.92
D-11 Treated	July 22 9.55 a.m. following fumigation	7,200	88	46	12.1	Upper Lower Average	13.4 11.1 12.2	52.2 48.4 50.3	30.2 29.4 29.8	4.2 11.1 7.7	2.25 2.40 2.33
A-15 Control	July 22 10.40 a.m.	8,100	84	59	7.4	Upper Lower Average	0 0 0	11.9 10.7 11.3	65.6 66.4 66.0	22.5 22.9 22.7	3.10 3.12 3.11
D-11 Treated	July 22 10.40 a.m. after fumigation	8,100	90	41	12.1	Upper Lower Average	9.7 24.8 17.2	57.4 55.4 56.4	24.5 14.8 19.7	8.4 5.0 6.7	2.32 2.00 2.16
<i>5.80 p.p.m. for ¼ hr. (11.16-11.30 a.m.) second sulphur dioxide treatment</i>											
A-15 Control	July 22 11.30 a.m.	8,800	83	66	7.4	Upper Lower Average	0 0 0	23.2 20.3 21.7	56.8 46.4 51.6	20.0 33.3 26.7	2.97 3.13 3.05
D-11 Treated	July 22 11.30 a.m. following 2nd fumigation	8,800	94	41	12.1	Upper Lower Average	13.9 50.8 32.3	49.6 43.7 46.7	25.2 4.6 14.9	11.3 0.9 6.1	2.34 1.55 1.95
A-15 Control	July 22 1.30 p.m.	8,300	82	61	7.4	Upper Lower Average	1.6 1.8 1.7	40.6 26.0 33.3	48.0 56.8 52.4	9.8 15.4 12.6	2.66 2.86 2.76
D-11 Treated	July 22 1.30 p.m. after 2nd fumigation	8,300	94	43	12.1	Upper Lower Average	25.3 56.6 40.9	67.3 33.1 50.2	6.8 8.7 7.8	0.6 1.6 1.1	1.83 1.55 1.69

TABLE III
EFFECT OF HIGH CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF THE STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft.-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
C-7 Control	July 15 7.30 a.m.	2,600	72	65	10.6	Upper	0	40.8	56.5	2.7	2.62
						Lower	0	50.0	48.2	1.8	2.52
						Average	0	45.4	52.3	2.3	2.57
D-7 Treated	July 15 7.30 a.m. before fumigation	2,600	72	65	11.2	Upper	0	50.0	41.2	8.8	2.59
						Lower	1.0	49.0	39.6	10.4	2.60
						Average	0.5	49.5	40.4	9.6	2.60
Sulphur dioxide treatment: 2.96 p.p.m. for 4 hr. (8.00 a.m.-12.00 noon)											
C-7	July 15 11.30 a.m.	10,500	80	64	10.6	Upper	6.1	48.5	30.3	15.1	2.54
						Lower	0.8	43.0	33.1	23.1	2.78
						Average	3.5	45.7	31.7	19.1	2.66
D-7 Treated, no visible injury	July 15 11.30 a.m. during fumigation	10,500	87	57	11.2	Upper	53.2	46.8	0	0	1.47
						Lower	68.7	36.3	0	0	1.36
						Average	58.5	41.5	0	0	1.42
D-7 Treated, visible injury	11.30 a.m. during fumigation	10,500	87	57	11.2	Upper	51.1	48.9	0	0	1.49
						Lower	68.3	31.7	0	0	1.32
						Average	59.7	40.3	0	0	1.41
C-7 Control	July 15 3.30 p.m.	4,300	85	50	10.6	Upper	3.5	57.9	35.1	3.5	2.39
						Lower	1.0	65.0	31.0	3.0	2.36
						Average	2.2	61.5	33.0	3.3	2.38
D-7 Treated	July 15 3.30 p.m. after fumigation	4,300	85	50	11.2	Upper	28.6	71.4	0	0	1.74
						Lower	37.2	62.8	0	0	1.60
						Average	32.9	67.1	0	0	1.67

TABLE IV
EFFECT OF HIGH CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF THE STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
D-4 Control	July 17 7.30 a.m.	1,900	70	77	12.5	Upper	0	39.7	53.5	6.8	2.67
						Lower	0	55.9	39.7	4.4	2.49
						Average	0	47.8	46.6	5.6	2.58
C-4 Treated	July 17 7.30 a.m. before fumigation	1,900	70	77	13.6	Upper	1.6	62.3	36.1	0	2.35
						Lower	2.4	60.0	36.4	1.2	2.37
						Average	2.0	61.1	36.3	0.6	2.36
Sulphur dioxide treatment: 1.47 p.m. for 4 hr. (8.00 a.m.-12.00 noon)											
D-4 Control	July 17 11.30 a.m.	9,600	85	70	12.5	Upper	2.7	55.7	38.9	2.7	2.42
						Lower	2.4	49.6	44.8	3.2	2.49
						Average	2.5	52.7	41.8	3.0	2.45
C-4 Treated	July 17 11.30 a.m. during fumigation	9,600	93	68	13.6	Upper	34.1	60.2	5.7	0	1.71
						Lower	27.1	69.6	3.3	0	1.76
						Average	30.6	64.9	4.5	0	1.74
D-4 Control	July 17 2.45 p.m.	4,500	86	70	12.5	Upper	0	50.0	44.5	5.5	2.56
						Lower	0	61.6	35.7	2.7	2.41
						Average	0	55.8	40.1	4.1	2.48
C-4 Treated	July 17 2.45 p.m. after fumigation	4,500	86	70	13.6	Upper	9.4	80.5	10.2	0	2.01
						Lower	8.7	81.1	10.2	0	2.02
						Average	9.0	80.8	10.2	0	2.02

TABLE V
EFFECT OF HIGH CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF THE STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
C-5 Control	July 16 7.30 a.m.	2,700	72	58	12.1	Upper	0	51.8	43.6	4.6	2.53
						Lower	0.9	38.3	47.7	13.1	2.73
						Average	0.5	45.0	45.6	8.9	2.63
D-5 Treated	July 16 7.30 a.m. before fumigation	2,700	72	58	11.3	Upper	0	41.2	47.4	11.4	2.70
						Lower	1.2	44.1	47.6	7.1	2.61
						Average	0.6	42.6	47.5	9.3	2.66
Sulphur dioxide treatment: 1.27 p.m. for 4 hr. (8.00 a.m.-12.00 noon)											
C-5 Control	July 16 11.30 a.m.	10,500	79	60	12.1	Upper	0	46.5	50.4	3.1	2.57
						Lower	0.8	38.8	56.8	3.6	2.64
						Average	0.4	42.6	53.6	3.4	2.60
D-5 Treated	July 16 11.30 a.m. during fumigation	10,500	84	59	11.3	Upper	48.1	51.9	0	0	1.52
						Lower	59.9	38.3	1.8	0	1.42
						Average	54.0	45.1	0.9	0	1.47
C-5 Control	July 16 3.30 p.m.	4,800	89	46	12.1	Upper	1.6	60.6	37.8	0	2.36
						Lower	0.8	50.7	45.2	3.3	2.51
						Average	1.2	55.7	41.5	1.6	2.44
D-5 Treated	July 16 3.30 p.m. after fumigation	4,800	89	46	11.3	Upper	0.8	98.4	0.8	0	2.00
						Lower	37.5	60.6	1.9	0	1.65
						Average	19.1	79.5	1.4	0	1.83

TABLE VI
EFFECT OF HIGH CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF THE STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
C-7 Control	July 15, 7.30 a.m.	2,600	72	65	10.6	Upper	0	40.8	56.5	2.7	2.62
						Lower	0	50.0	48.2	1.8	2.52
						Average	0	45.4	52.3	2.3	2.57
D-17 Treated	July 15, 7.30 a.m. before fumigation	2,600	72	65	11.7	Upper	0	64.3	33.3	2.4	2.38
						Lower	0	51.4	46.6	2.0	2.51
						Average	0	57.8	40.0	2.2	2.45
Sulphur dioxide treatment: 1.04 p.p.m. for 4 hr. (8.00 a.m.-12.00 noon)											
C-7 Control	July 15, 11.30 a.m.	10,500	80	64	10.6	Upper	6.1	48.5	30.3	15.1	2.54
						Lower	0.8	43.0	33.1	23.1	2.78
						Average	3.5	45.7	31.7	19.1	2.66
D-17 Treated	July 15, 11.30 a.m. during fumigation	10,500	84	46	11.7	Upper	26.2	73.8	0	0	1.74
						Lower	42.2	56.0	1.8	0	1.60
						Average	34.2	64.9	0.9	0	1.67
C-7 Control	July 15, 3.30 p.m.	4,300	85	50	10.6	Upper	3.5	57.9	35.1	3.5	2.39
						Lower	1.0	65.0	31.0	3.0	2.36
						Average	2.2	61.5	33.0	3.3	2.38
D-17 Treated	July 15, 3.30 p.m. after fumigation	4,300	85	50	11.7	Upper	0.9	73.6	21.8	3.7	2.28
						Lower	14.1	62.6	20.2	3.1	2.12
						Average	7.5	68.1	21.0	3.4	2.20

TABLE VII
EFFECT OF HIGH CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
G-9 Control	Aug. 11 8.00 a.m.	3,200	78	68	12.4	Upper	0	54.4	34.6	11.0	2.57
						Lower	0	44.4	39.4	16.2	2.70
						Average	0	49.4	37.0	13.6	2.63
G-6 Treated	Aug. 11 8.00 a.m. before fumigation	3,200	78	68	11.6	Upper	0.6	56.4	36.5	6.5	2.49
						Lower	0.7	48.6	37.3	13.4	2.64
						Average	0.7	52.5	36.9	9.9	2.57
G-8 Treated	Aug. 11 8.00 a.m. before fumigation	200	78	68	10.9	Upper	0.6	56.2	36.3	6.9	2.49
						Lower	4.6	51.7	24.4	19.3	2.58
						Average	2.6	53.9	30.4	13.1	2.53
Sulphur dioxide treatment: 1.00 for 7 hr. (8.15 a.m. to 3.15 p.m.)											
G-9 Control	Aug. 11 10.00 a.m.	4,800	83	61	12.4	Upper	0	64.9	31.7	3.4	2.39
						Lower	0	34.4	41.8	23.8	2.89
						Average	0	49.6	36.8	13.6	2.64
G-6 Treated	Aug. 11 10.00 a.m. after 1.75 hr. fumigation	4,800	81	62	11.6	Upper	0	92.7	7.3	0	2.07
						Lower	0	32.7	51.8	15.5	2.82
						Average	0	62.7	29.5	7.8	2.44
Sulphur dioxide treatment: 0.97 for 7 hr. (8.15 a.m. to 3.15 p.m.)											
G-8 Treated	Aug. 11 10.00 a.m. after 1.75 hr. fumigation	200	80	60	10.9	Upper	5.1	74.7	20.2	0	2.15
						Lower	14.7	55.2	18.7	11.4	2.27
						Average	9.9	64.9	19.5	5.7	2.21

TABLE VII—Continued

Plot	Time of collection of strips	Light, ft.-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
G-9 Control	Aug. 11 1.15 p.m.	7,600	92	53	12.4	Upper	2.5	47.8	45.9	3.8	2.51
						Lower	1.7	34.5	53.4	10.4	2.72
						Average	2.1	41.1	49.7	7.1	2.61
G-6 Treated	Aug. 11 1.15 p.m. after 5 hr. fumigation	7,600	90	55	11.6	Upper	31.3	68.7	0	0	1.69
						Lower	64.8	35.2	0	0	1.35
						Average	48.0	52.0	0	0	1.52
G-8 Treated	Aug. 11 1.15 p.m. after 5 hr. fumigation	200	87	54	10.9	Upper	81.4	18.6	0	0	1.19
						Lower	88.2	11.8	0	0	1.12
						Average	84.8	15.2	0	0	1.16
G-9 Control	Aug. 11 3.15 p.m.	3,600	94	49	12.4	Upper	1.2	28.9	47.4	22.5	2.91
						Lower	0	26.2	37.5	36.3	3.10
						Average	0.6	27.5	42.5	29.4	3.00
G-6 Treated	Aug. 11 3.15 p.m. after 7 hr. fumigation	3,600	94	49	11.6	Upper	18.5	51.3	28.1	2.1	2.14
						Lower	46.4	32.8	16.0	4.8	1.79
						Average	32.4	42.1	22.0	3.5	1.97
G-8 Treated	Aug. 11 3.15 p.m. after 7 hr. fumigation	200	87	46	10.9	Upper	27.1	72.9	0	0	1.73
						Lower	68.4	31.6	0	0	1.32
						Average	47.7	52.3	0	0	1.53

TABLE VIII
EFFECT OF MEDIUM CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
Sulphur dioxide treatment: 0.89 p.p.m. for 20 hr. (8.30 a.m. Aug. 12-4.30 a.m. Aug. 13)											
G-7 Control	Aug. 12 10.30 a.m.	6,000	86	59	11.1	Upper	0	31.8	65.5	2.7	2.71
						Lower	0.6	56.1	39.4	3.9	2.47
						Average	0.3	43.9	52.5	3.3	2.59
H-5 Treated	Aug. 12 10.30 a.m. after 2 hr. fumigation	6,000	86	59	11.7	Upper	0.9	44.4	53.8	0.9	2.55
						Lower	2.8	47.4	44.9	4.6	2.51
						Average	1.8	46.1	49.3	2.8	2.53
Sulphur dioxide treatment: 0.84 p.p.m. for 20 hr. (8.30 a.m. Aug. 12-4.30 a.m. Aug. 13)											
G-11 Treated	Aug. 12 10.30 a.m. after 2 hr. fumigation	200	82	64	12.2	Upper	17.2	82.8	0	0	1.83
						Lower	29.8	67.9	2.3	0	1.73
						Average	23.5	75.3	1.2	0	1.78
G-7 Control	Aug. 12 4.30 p.m.	600	88	56	11.1	Upper	0	89.0	11.0	0	2.11
						Lower	0.8	50.4	43.0	5.8	2.54
						Average	0.4	69.7	27.0	2.9	2.32
H-5 Treated	Aug. 12 4.30 p.m. after 8 hr. fumigation	600	88	56	11.7	Upper	2.1	75.0	20.8	2.1	2.23
						Lower	13.4	58.2	25.4	3.0	2.18
						Average	7.7	66.6	23.1	2.6	2.21
G-11 Treated	Aug. 12 4.30 p.m. after 8 hr. fumigation	100	85	58	12.2	Upper	19.2	80.8	0	0	1.81
						Lower	51.8	48.2	0	0	1.48
						Average	35.5	64.5	0	0	1.65

TABLE VIII—Continued

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
G-7 Control	Aug. 12 10.30 p.m.	0	77	49	11.1	Upper	85.4	14.6	0	0	1.15
						Lower	77.4	22.6	0	0	1.23
						Average	81.4	18.6	0	0	1.19
H-5 Treated	Aug. 12 10.30 p.m. after 14 hr. fumigation	0	77	49	11.7	Upper	84.5	15.5	0	0	1.16
						Lower	82.2	17.8	0	0	1.18
						Average	83.3	16.7	0	0	1.17
G-11	Aug. 12 10.30 p.m. after 14 hr. fumigation	0	74	50	12.2	Upper	89.8	10.2	0	0	1.10
						Lower	96.0	4.0	0	0	1.04
						Average	92.9	7.1	0	0	1.07
G-7 Control	Aug. 13 4.30 a.m.	25	65	64	11.1	Upper	13.5	85.4	1.1	0	1.88
						Lower	26.0	66.0	8.0	0	1.82
						Average	19.7	75.7	4.6	0	1.85
H-5 Treated	Aug. 13 4.30 a.m. after 20 hr.	25	65	64	11.7	Upper	23.4	76.6	0	0	1.77
						Lower	27.8	71.3	0.9	0	1.73
						Average	25.6	73.9	0.5	0	1.75
G-11 Treated	Aug. 13 4.30 a.m. after 20 hr. fumigation	25	64	65	12.2	Upper	19.1	80.9	0	0	1.81
						Lower	16.2	74.8	9.0	0	1.93
						Average	17.6	77.9	4.5	0	1.87

TABLE IX
EFFECT OF MEDIUM CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
C-5 Control	July 16 7.30 a.m.	2,700	72	58	12.1	Upper	0	51.8	43.6	4.6	2.53
						Lower	0.9	38.3	47.7	13.1	2.73
						Average	0.5	45.0	45.6	8.9	2.63
D-15 Treated	July 16 7.30 a.m. before fumigation	2,700	70	64	12.8	Upper	2.0	53.0	45.0	0	2.43
						Lower	1.0	70.1	28.9	0	2.28
						Average	1.5	61.5	37.0	0	2.36
Sulphur dioxide treatment: 0.76 p.p.m. for 4 hr. (8.00 a.m.-12.00 noon)											
C-5 Control	July 16 11.30 a.m.	10,500	79	60	12.1	Upper	0	46.5	50.4	3.1	2.57
						Lower	0.8	38.8	56.8	3.6	2.64
						Average	0.4	42.6	53.6	3.4	2.60
D-15 Treated	July 16 11.30 a.m. during fumigation	10,500	81	58	12.8	Upper	0	49.1	43.0	7.9	2.59
						Lower	0	35.2	47.3	17.5	2.82
						Average	0	42.1	45.2	12.7	2.70
C-5 Control	July 16 3.30 p.m.	4,800	89	46	12.1	Upper	1.6	60.6	37.8	0	2.36
						Lower	0.8	50.7	45.2	3.3	2.51
						Average	1.2	55.7	41.5	1.6	2.44
D-15 Treated	July 16 3.30 p.m. 3.5 hr. after fumigation	4,800	89	46	12.8	Upper	0.7	50.7	41.8	6.8	2.54
						Lower	2.5	64.1	30.0	3.4	2.34
						Average	1.6	57.4	35.9	5.1	2.44

TABLE X
EFFECT OF MEDIUM CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
C-15 Control	July 21 8.00 a.m.	3,700	80	61	12.7	Upper	0.8	13.2	86.0	0	2.85
						Lower	0	17.2	70.5	12.3	2.95
						Average	0.4	15.2	78.2	6.2	2.90
C-16 Treated	July 21 8.00 a.m. before fumigation	3,700	80	61	14.3	Upper	0	4.1	89.7	6.2	3.02
						Lower	0	6.1	46.3	47.6	3.41
						Average	0	5.1	68.0	26.9	3.21
Sulphur dioxide treatment: 0.57 p.p.m. for 4 hr. (8.45 a.m.-12.45 p.m.)											
C-15 Control	July 21 1.00 p.m.	6,000	79	74	12.7	Upper	0	6.2	87.6	6.2	3.00
						Lower	0	2.9	85.6	11.5	3.09
						Average	0	4.6	86.6	8.8	3.05
C-16 Treated	July 21 1.00 p.m. 15 min. after fumigation	6,000	84	70	14.3	Upper	0	0	82.4	17.6	3.18
						Lower	0	0	66.7	33.3	3.33
						Average	0	0	74.6	25.4	3.25

TABLE XI
EFFECT OF MEDIUM CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
D-4 Control	July 17 7.30 a.m.	1,900	70	77	12.5	Upper Lower Average	0 0 0	39.7 55.9 47.8	53.5 39.7 46.6	6.8 4.4 5.6	2.67 2.49 2.58
D-13 Treated	July 17 7.30 a.m. before fumigation	1,900	70	66	11.5	Upper Lower Average	0 1.5 0.7	46.5 44.8 45.7	49.6 50.0 49.8	3.9 3.7 3.8	2.58 2.56 2.57
Sulphur dioxide treatment: 0.44 p.p.m. for 4 hr. (8.00 a.m.-12.00 noon)											
D-4 Control	July 17 11.30 a.m.	9,600	85	70	12.5	Upper Lower Average	2.7 2.4 2.5	55.7 49.6 52.7	38.9 44.8 41.8	2.7 3.2 3.0	2.42 2.49 2.45
D-13 Treated	July 17 11.30 a.m. during fumigation	9,600	86	63	11.5	Upper Lower Average	2.0 1.5 1.8	52.5 45.1 48.8	42.5 49.6 46.0	3.0 3.8 3.4	2.46 2.56 2.51
D-4 Control	July 17 2.45 p.m.	4,500	86	70	12.5	Upper Lower Average	0 0 0	50.0 61.6 55.8	44.5 35.7 40.1	5.5 2.7 4.1	2.56 2.41 2.48
D-13 Treated	July 17 2.45 p.m. 2.75 hr. after fumigation	4,500	86	70	11.5	Upper Lower Average	0 1.0 0.5	52.2 34.0 43.1	45.3 51.0 48.1	2.5 14.0 8.3	2.51 2.78 2.64

TABLE XII

EFFECT OF MEDIUM CONCENTRATIONS OF SULPHUR DIOXIDE ON THE
BEHAVIOR OF THE STOMATA OF ALFALFA

Date	Time	Width of stomatal opening, microns	Light, ft-candles	Temp., °F.	Humidity, %	Sulphur dioxide treatment
July 9	11.00 a.m.—12.00 noon	10.2	2,500	80	60	0.40 p.p.m. for 171 hr. from 10.00 a.m. July 9 to 1.00 p.m. July 16—Plot A-1
	12.00 noon— 1.00 p.m.	10.2	2,300	80	60	
	1.00 p.m.— 2.00 p.m.	10.2	1,600	80	60	
	2.00 p.m.— 3.00 p.m.	10.2	1,900	82	54	
	3.00 p.m.— 4.00 p.m.	8.0-10.0	1,100	82	54	
	4.00 p.m.— 5.00 p.m.	6.0-8.0	800	76	64	
	5.00 p.m.— 6.00 p.m.	3.0	400	76	64	
	6.00 p.m.— 7.00 p.m.	Closing	No record	62	76	
	7.00 p.m.— 6.30 a.m.	Closed	—	62	76	
" 10	6.30 a.m.— 7.00 a.m.	Opening	No record	60	70	
	7.00 a.m.— 8.00 a.m.	3.4	"	60	70	
	8.00 a.m.— 9.00 a.m.	3.0-4.0	"	78	65	
	9.00 a.m.—10.00 a.m.	6.8-10.2	3,900	78	65	
	10.00 a.m.—11.00 a.m.	10.2	6,700	88	58	
	11.00 a.m.—12.00 noon	10.2	8,200	88	58	
	12.00 noon— 1.00 p.m.	10.2	8,600	88	58	
	1.00 p.m.— 2.00 p.m.	10.2	6,000	88	58	
	2.00 p.m.— 3.00 p.m.	10.2	7,400	86	48	
	3.00 p.m.— 4.00 p.m.	10.2	6,100	86	48	
	4.00 p.m.— 4.30 p.m.	10.2	1,500	76	50	
	4.30 p.m.— 5.30 p.m.	Closing	700	76	58	
" 11	5.30 p.m.	Closed				
	9.30 a.m.—10.00 a.m.	6.8	12,000	82	59	
	10.00 a.m.—11.00 a.m.	6.8	12,000	90	56	
	11.00 a.m.—12.00 noon	6.8	13,000	90	56	
	12.00 noon— 1.00 p.m.	10.2	10,800	90	56	
	1.00 p.m.— 2.00 p.m.	10.2	8,200	90	56	
	2.00 p.m.— 3.00 p.m.	8.0-9.0	4,300	90	52	
	3.00 p.m.— 4.00 p.m.	3.4	3,200	90	52	
	4.00 p.m.— 5.30 p.m.	Closing	2,800	95	50	
	5.30 p.m.— 5.00 a.m.	Closed	300	84	64	
" 12	5.00 a.m.— 6.00 a.m.	Opening	—	—	—	
	6.00 a.m.— 7.00 a.m.	3.4	1,700	78	60	
	7.00 a.m.— 8.00 a.m.	3.4	7,200	78	60	
	8.00 a.m.— 9.00 a.m.	6.0-9.0	14,000	96	58	
	9.00 a.m.—10.00 a.m.	10.2	14,000	96	58	
	10.00 a.m.—11.00 a.m.	10.2	11,900	97	58	
	11.00 a.m.—12.00 noon	10.2	11,900	97	58	
	12.00 noon— 1.00 p.m.	10.2	9,500	97	58	
	1.00 p.m.— 2.00 p.m.	10.2	6,700	97	58	
	2.00 p.m.— 3.00 p.m.	8.0	5,000	94	52	
	3.00 p.m.— 4.00 p.m.	6.8	3,000	94	52	
	4.00 p.m.— 5.00 p.m.	3.4	1,700	96	50	
	5.00 p.m.— 6.00 p.m.	Closing	300	96	50	
	6.00 p.m.	Closed	150	90	62	

TABLE XII—Continued

Date	Time	Width of stomatal opening, microns	Light, ft-candles	Temp., °F.	Humidity, %	Sulphur dioxide treatment
July 13	No record till 9.15 a.m.					
	9.15 a.m.—10.00 a.m.	6.8	9,600	90	64	
	10.00 a.m.—11.00 a.m.	6.8	12,800	98	58	
	11.00 a.m.—12.00 noon	6.8	14,000	98	58	
	12.00 noon— 1.00 p.m.	6.8	12,800	98	58	
	1.00 p.m.— 2.00 p.m.	6.8	9,100	98	58	
	2.00 p.m.— 3.00 p.m.	5.0	7,800	96	54	
	3.00 p.m.— 4.00 p.m.	5.0	4,800	96	54	
	4.00 p.m.— 5.00 p.m.	3.4	2,400	94	52	
	5.00 p.m.— 6.00 p.m.	Closing	500	94	52	
	6.00 p.m.	Closed	100	90	64	
" 15	9.30 a.m.—10.00 a.m.	3.4	1,500	90	72	
	10.00 a.m.—11.00 a.m.	3.4	900	78	58	
	11.00 a.m.—12.00 noon	4.0	900	78	58	
	12.00 noon— 1.00 p.m.	3.4	3,000	78	58	
	1.00 p.m.— 2.00 p.m.	3.4	3,000	78	58	
	2.00 p.m.— 4.00 p.m.	Closing	2,400	—	—	
	4.00 p.m.— 5.00 p.m.	Closed	600	82	50	
	5.00 p.m.— 5.00 a.m.	Closed	100	82	50	
" 16	5.00 a.m.— 6.00 a.m.	Opening	500	83	72	
	6.00 a.m.— 7.00 a.m.	1.0-2.0	1,200	83	72	
	7.00 a.m.— 8.00 a.m.	3.4	3,900	88	68	
	8.00 a.m.— 9.00 a.m.	5.0	6,400	93	64	
	9.00 a.m.—10.00 a.m.	6.8	7,400	93	64	
	10.00 a.m.—11.00 a.m.	6.8	8,700	97	46	
	11.00 a.m.—12.00 noon	6.8	10,000	97	46	
	12.00 noon— 1.00 p.m.	5.0-6.0	14,000	97	46	

TABLE XIII
THE EFFECT OF LOW CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
A-15 Control	July 22 8.00 a.m.	3,000	82	76	7.4	Upper	0	8.5	21.9	69.6	3.61
						Lower	0	15.6	60.4	24.0	3.08
						Average	0	12.1	41.1	46.8	3.34
B-15 Treated	July 22 8.00 a.m. before fumigation	3,000	80	72	8.1	Upper	0	26.0	52.1	21.9	2.94
						Lower	0	24.1	46.8	29.1	2.98
						Average	0	25.1	49.4	25.5	2.96
1st Sulphur dioxide treatment: 0.29 p.p.m. for 4 hr. (8.00 a.m.-12.00 noon)											
A-15 Control	July 22 11.30 a.m.	8,000	83	66	7.4	Upper	0	23.1	56.9	20.0	2.97
						Lower	0	20.4	46.3	33.3	3.13
						Average	0	21.7	51.6	26.7	3.05
B-15 Treated	July 22 11.30 a.m. during 1st fumigation	8,000	84	69	8.1	Upper	0	31.2	41.7	27.1	2.96
						Lower	0	19.2	50.0	30.8	3.11
						Average	0	25.2	45.9	28.9	3.04
A-15 Control	July 23 8.00 a.m.	3,200	86	57	7.4	Upper	0	35.5	49.5	15.0	2.80
						Lower	0	20.2	59.6	20.2	3.00
						Average	0	27.8	54.6	17.6	2.90
B-15 Treated	July 23 8.00 a.m. before 2nd fumigation	3,200	88	54	8.1	Upper	0.7	26.6	65.0	7.7	2.80
						Lower	0	25.2	61.8	13.0	2.88
						Average	0.4	25.9	63.4	10.3	2.84

TABLE XIII—Continued

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
2nd Sulphur dioxide treatment: 0.27 p.p.m. for 4 hr. (8.00 a.m.-12.00 noon)											
A-15 Control	July 23 11.30 a.m.	8,800	78	63	7.4	Upper Lower Average	0 0 0	10.0 14.6 12.3	73.0 72.5 72.7	17.0 12.9 15.0	3.07 2.98 3.02
B-15 Treated	July 23 11.30 a.m. during 2nd fumigation	3,800	80	64	8.1	Upper Lower Average	0 1.0 0.5	13.2 15.7 14.5	71.5 71.5 71.5	15.3 11.8 13.5	3.02 2.94 2.98
A-15 Control	July 24 8.00 a.m.	3,300	73	57	7.4	Upper Lower Average	0 1.0 0.5	5.6 7.5 6.5	77.8 56.6 67.2	16.6 34.9 25.8	3.11 3.25 3.18
B-15 Treated	July 24 8.00 a.m. before 3rd fumigation	3,300	76	59	8.1	Upper Lower Average	0 0.9 0.5	9.0 6.1 7.5	76.0 57.0 66.5	15.0 36.0 25.5	3.06 3.28 3.17
3rd Sulphur dioxide treatment: 0.24 p.p.m. for 4 hr. (8.00 a.m.-12.00 noon)											
A-15 Control	July 24 11.30 a.m.	10,800	78	71	7.4	Upper Lower Average	1.6 0.7 1.2	23.6 9.6 16.6	72.4 64.0 68.2	2.4 25.7 14.0	2.76 3.15 2.95
B-15 Treated	July 24 11.30 a.m. during 3rd fumigation	10,800	77	71	8.1	Upper Lower Average	0.7 0 0.4	48.6 15.9 32.2	49.3 52.1 50.7	1.4 32.0 16.7	2.52 3.16 2.84

TABLE XIV
THE EFFECT OF LOW CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF STOMATA OF ALFALFA

Plot	Time of collection of strips	Light, ft-candles	Temp., °F.	Humidity, %	Soil moisture, %	Epidermis	Percentage distribution of stomata in the following classes				Index
							(1)	(2)	(3)	(4)	
Sulphur dioxide treatment: 0.168 p.p.m. for 60 hr. (July 18-20)											
H-10 Control	July 20 11.30 a.m.	9,600	90	50	13.1	Upper	0	13.8	36.2	50.0	3.36
						Lower	0	14.6	32.0	53.4	3.39
						Average	0	14.2	34.1	51.7	3.38
H-11 Treated	July 20 11.30 a.m. at end of fumigation	9,600	90	50	14.2	Upper	0	4.2	27.6	68.2	3.62
						Lower	1.0	17.4	24.8	56.8	3.38
						Average	0.5	11.4	26.2	61.9	3.50

TABLE XV
THE EFFECT OF LOW CONCENTRATIONS OF SULPHUR DIOXIDE ON THE BEHAVIOR OF STOMATA OF ALFALFA

Date	Time	Width of stomatal opening, microns		Light, ft-candles	Carbon dioxide assimilation, gm. per hr.		Temp., °F.	Humidity, %	Sulphur dioxide treatment
		Plot I-11	Plot I-10		Plot I-11	Plot I-10			
		Fumigated	Control		Fumigated	Control			
Aug. 1	11.00 a.m.—12.00 noon	6.8	6.8	1,700	—	—	72	80	0.14 p.p.m. for 196½ hr. from 11.00 a.m. July 31, to 3.20 p.m. August 2; and from 3.00 p.m. August 3, to 4.00 p.m. August 9.
	12.00 noon—1.00 p.m.	6.8	6.8	1,000	3.8	5.2	72	80	
	1.00 p.m.—2.00 p.m.	6.8	6.8	No record	5.1	4.7	72	80	
	2.00 p.m.—3.00 p.m.	6.8	6.8	No record	6.4	6.9	75	80	
	3.00 p.m.—4.00 p.m.	6.8	6.8	3,500	7.2	7.9	75	80	
	4.00 p.m.—5.00 p.m.	Nearly closed	3.4	2,400	5.1	5.1	80	80	
	5.00 p.m.—5.00 a.m.	Closed	Closed	—	—	—	57	88	
	5.30 a.m.—6.00 a.m.	Opening	—	No record	—	—	72	74	
" 2	6.00 a.m.—7.00 a.m.	2.0	No record	900	5.1	5.2	72	74	
	7.00 a.m.—8.00 a.m.	3.0	No record	2,000	5.1	5.2	72	74	
	8.00 a.m.—9.00 a.m.	6.8	No record	4,500	5.9	6.1	72	71	
	9.00 a.m.—10.00 a.m.	6.8	No record	7,100	6.9	6.9	92	71	
	10.00 a.m.—11.00 a.m.	10.2	No record	11,200	7.7	8.4	92	69	
	11.00 a.m.—12.00 noon	10.2	10.2	15,800	—	1.6	97	69	
	12.00 noon—1.00 p.m.	10.2	10.2	15,800	—	2.6	97	69	
	1.00 p.m.—2.00 p.m.	6.8	10.2	12,000	—	4.2	97	69	
" 3	2.00 p.m.—3.00 p.m.	6.8	10.2	10,700	—	2.0	91	57	
	3.00 p.m.—4.00 p.m.	6.8	6.8	6,700	—	0.6	91	57	
	4.00 p.m.—5.00 p.m.	4.0	5.0	600	—	2.8	95	53	
	5.00 p.m.—5.30 p.m.	3.0	2.0	500	—	—	95	53	
	5.30 p.m.—5.00 a.m.	Closed	Closed	500	—	—	78	80	
	5.00 a.m.—6.00 a.m.	Opening	Opening	250	—	—	60	92	
	6.00 a.m.—7.00 a.m.	6.8	3.4	800	—	—	63	93	
	7.00 a.m.—8.00 a.m.	6.8	6.8	1,000	1.5	1.5	63	93	
	8.00 a.m.—9.00 a.m.	8.0	10.2	1,200	2.1	1.3	73	87	
	9.00 a.m.—10.00 a.m.	10.2	10.2	7,800	5.6	8.7	73	87	
	10.00 a.m.—11.00 a.m.	10.2	10.2	10,700	13.9	13.9	90	66	
	11.00 a.m.—12.00 noon	10.2	10.2	5,000	8.2	8.5	90	66	
	12.00 noon—1.00 p.m.	8.0	5.0	1,900	8.2	8.2	90	66	
	1.00 p.m.—2.00 p.m.	6.3	3.0	Rain	5.4	5.6	90	66	
	2.00 p.m.—3.00 p.m.	4.0	2.0	Rain	0.1	0.1	70	81	
	3.00 p.m.—4.00 p.m.	4.0	2.0	—	1.0	1.0	70	81	
	4.00 p.m.—5.00 p.m.	Closing	Closing	—	3.9	3.9	67	84	
	5.00 p.m.—	Closed	Closed	—	—	—	—	—	

TABLE XV—Continued

Date	Time	Width of stomatal opening, microns			Light, ft.-candles	Carbon dioxide assimilation, gm. per hr.			Temp., °F.	Humidity, %	Sulphur dioxide treatment
		Plot I-11	Plot I-10	Control		Plot I-11	Fumigated	Control			
Aug. 5	2.00 p.m.—	6.8	6.8	6.8	2,600	6.7	—	9.1	84	69	
	3.00 p.m.—	6.8	5.0	5.0	3,500	6.1	—	8.5	81	69	
	4.00 p.m.—	3.4	3.4	3.4	1,500	6.1	—	6.1	81	73	
	5.00 p.m.—	2.0	Closing	Closing	1,000	5.2	—	6.1	81	73	
	6.00 p.m.—	Closing	Closing	Closing	150	2.6	—	3.4	77	72	
	7.00 p.m.—	Closing	Closing	Closing	50	—	—	—	77	72	
	5.00 a.m.—	Opening	Opening	Opening	250	—	—	—	51	95	
	6.00 a.m.—	4.0	3.0	3.0	700	—	—	—	77	75	
	7.00 a.m.—	5.0	3.0	3.0	2,000	—	—	—	77	75	
	8.00 a.m.—	6.8	6.8	6.8	3,700	—	—	—	91	66	
" 6	9.00 a.m.—	10.2	10.2	10.2	5,000	6.7	—	8.8	91	66	
	10.00 a.m.—	10.2	10.2	10.2	4,500	7.0	—	7.7	95	60	
	11.00 a.m.—	10.2	10.2	10.2	2,500	7.7	—	8.4	95	60	
	12.00 noon—	10.2	10.2	10.2	6,000	8.2	—	8.8	95	60	
	1.00 p.m.—	10.2	10.2	10.2	5,000	7.0	—	8.4	95	60	
	2.00 p.m.—	6.8	6.8	6.8	4,500	—	—	—	93	59	
	3.00 p.m.—	6.8	6.8	6.8	3,900	—	—	—	93	57	
	4.00 p.m.—	5.0	—	—	1,900	—	—	—	90	57	
	5.00 p.m.—	Closing	Closing	Closing	500	—	—	—	90	57	
	5.30 p.m.—	Closing	Closing	Closing	400	—	—	—	74	57	
" 7	5.00 a.m.—	Opening	Opening	Opening	150	—	—	—	53	90	
	6.00 a.m.—	4.0	3.0	3.0	600	2.6	—	3.2	80	73	
	7.00 a.m.—	5.0	3.0	3.0	1,600	4.2	—	4.2	80	73	
	8.00 a.m.—	6.8	6.8	6.8	2,400	4.6	—	4.7	88	69	
	9.00 a.m.—	10.2	10.2	10.2	4,100	3.8	—	4.6	88	69	
	10.00 a.m.—	10.2	10.2	10.2	4,500	3.8	—	5.1	97	61	
	11.00 a.m.—	10.2	10.2	10.2	5,600	4.8	—	6.0	97	61	
	12.00 noon—	10.2	10.2	10.2	6,000	5.7	—	6.4	97	61	
	1.00 p.m.—	10.2	10.2	10.2	5,300	6.4	—	7.0	97	61	
	2.00 p.m.—	10.2	10.2	10.2	5,000	2.8	—	6.9	96	60	
" 8	3.00 p.m.—	10.2	10.2	10.2	3,700	3.3	—	3.8	96	60	
	4.00 p.m.—	3.4	3.4	3.4	1,900	2.0	—	2.8	93	61	
	5.00 p.m.—	Closing	Closing	Closing	1,400	—	—	2.3	93	61	
	6.00 p.m.—	Closing	Closing	Closing	—	—	—	—	—	—	
	5.00 a.m.—	Opening	Opening	Opening	No record	5.1	—	4.4	57	85	
	6.00 a.m.—	4.0	No record	No record	No record	1.8	—	1.1	78	79	
	7.00 a.m.—	5.0	No record	No record	No record	2.3	—	3.8	78	79	
	8.00 a.m.—	6.8	No record	No record	3,000	2.8	—	4.1	87	64	

TABLE XVI
EFFECT OF LOW CONCENTRATIONS OF SULPHUR DIOXIDE ON THE
BEHAVIOR OF THE STOMATA OF ALFALFA

Date	Time	Width of stomatal opening, microns		Light, ft-candles	Temp., °F.	Humi-dity, %	Sulphur dioxide treatment
		G-8 Fumigated	G-7 Control				
July 24	4.45 a.m.— 5.00 a.m.	No record	Opening	50	71	93	0.12 p.m. for 234 hr. from 3.20 p.m. July 19 to 8.45 p.m. July 29.
	6.00 a.m.— 7.00 a.m.		3.4	500	80	92	
	7.00 a.m.— 8.00 a.m.		4.0-5.0	2,200	80	92	
	8.00 a.m.— 9.00 a.m.		8.0	4,800	97	75	
	9.00 a.m.— 10.00 a.m.		10.2	5,000	97	75	
	10.00 a.m.— 11.00 a.m.	10.2	10.2	8,700	105	75	
	11.00 a.m.— 12.00 noon		7.0-8.0	8,700	105	75	
	12.00 noon— 1.00 p.m.		6.8	8,700	105	75	
	1.00 p.m.— 2.00 p.m.		6.8	7,800	105	75	
	2.00 p.m.— 3.00 p.m.		6.8	6,400	108	68	
	3.00 p.m.— 4.00 p.m.		6.8	2,400	108	68	
	4.00 p.m.— 4.30 p.m.	Closing	Closing	4,300	91	75	
	5.00 p.m.— 6.00 p.m.	Closed	Closed				
" 25	8.00 a.m.— 9.00 a.m.	6.8	6.8	3,500	111	65	
	9.00 a.m.— 10.00 a.m.	6.8	8.0	6,700	111	65	
	10.00 a.m.— 11.00 a.m.	6.8	9.0	7,400	108	66	
	11.00 a.m.— 12.00 noon	10.2	10.2	8,600	108	66	
	12.00 noon— 1.00 p.m.	10.2	10.2	3,900	108	66	
	1.00 p.m.— 2.00 p.m.	10.2	10.2	3,500	108	66	
	2.00 p.m.— 3.00 p.m.	10.2	10.2	3,900	90	72	
	3.00 p.m.— 4.00 p.m.	6.8	8.0	5,000	90	72	
	4.00 p.m.— 5.00 p.m.	4.0	6.8	1,800	90	85	
	5.00 p.m.— 6.00 p.m.	3.4	3.4	900	90	85	
" 26	6.00 p.m.— 7.00 p.m.	Closed	Closed	800	79	85	
	5.15 a.m.— 6.00 a.m.	Opening	—	No record	64	94	
	6.00 a.m.— 7.00 a.m.	3.4	—	1,200	97	79	
	7.00 a.m.— 8.00 a.m.	4.0	No record	4,100	97	79	
	8.00 a.m.— 9.00 a.m.	6.8		6,000	100	65	
	9.00 a.m.— 10.00 a.m.	10.2		7,200	100	65	
	10.00 a.m.— 11.00 a.m.	10.2		10,100	93	55	
	11.00 a.m.— 12.00 noon	10.2		10,700	93	55	
	12.00 noon— 1.00 p.m.	10.2		10,700	93	55	
	1.00 p.m.— 2.00 p.m.	4.0	Closing	9,100	93	55	
	2.00 p.m.— 3.00 p.m.	3.4		3,900	94	51	
	3.00 p.m.— 4.00 p.m.	3.4		2,000	94	51	
	4.00 p.m.— 4.20 p.m.	Closing		1,500	87	49	
	4.20 p.m.	Closed		1,400	87	49	
" 27	5.30 a.m.— 6.00 a.m.	3.4	Opening				
	6.00 a.m.— 7.00 a.m.		3.4	400	70	96	
	7.00 a.m.— 8.00 a.m.		3.4	1,100	70	96	
	8.00 a.m.— 9.00 a.m.		6.8	1,300	81	97	
	9.00 a.m.— 10.00 a.m.		10.2	5,000	81	97	
	10.00 a.m.— 11.00 a.m.	9.0	10.2	1,700	76	83	
	11.00 a.m.— 12.00 noon	10.2	10.2	600	76	83	
	12.00 noon— 1.00 p.m.	10.2	10.2	7,400	76	83	
	1.00 p.m.— 2.00 p.m.	10.2	10.2	3,000	76	83	
	2.00 p.m.— 3.00 p.m.	10.2	10.2	1,100	82	83	

CHAPTER XIII

EXPERIMENTS ON YIELD OF BARLEY AND ALFALFA

BY MORRIS KATZ AND G. A. LEDINGHAM

Introduction and Literature Review

Numerous investigators have stressed the injurious effects of sulphur dioxide on vegetation, and the early work on this subject is replete with details of the damage caused to growth in the vicinity of industrial and smelting works. Until recently, however, there has been a noticeable lack of data on the effect of concentrations of sulphur dioxide too low to cause visible symptoms. As this early work was confined mainly to field observations and experiments with relatively high concentrations of sulphur dioxide which would be bound to prove destructive to plants, the belief arose that this gas is harmful in any concentration no matter how dilute, and resulted in the theory of "invisible injury". Although no convincing experimental evidence was brought forward to support this view, the proponents of the invisible injury theory maintained that the gas was harmful at all times and in all concentrations, the adverse effect being manifested in a reduction in yield or disturbance of the assimilative processes. Such views will be found principally in the works of Wieler (14) and Stoklasa (9). A summary of these early investigations and review of the literature on smoke damage are given by Haselhoff, Bredemann and Haselhoff (1), and Janson (4) has recently discussed the question of invisible damage with arguments based on field observations.

The implications of the invisible injury theory as pointed out by Swain (11) are of far-reaching importance to agricultural and industrial interests, as the larger part of areas subjected to visitations of sulphur dioxide are exposed to concentrations too dilute to cause the visible symptoms associated with acute and chronic injury. As shown in Chapter II, sulphur dioxide in concentrations lower than 0.20 p.p.m. may be found in the atmosphere for extended periods not only in recognized smelter areas but also in rural districts adjacent to industrial centres. In fact, it would be difficult to find any area entirely free from traces of sulphur dioxide in the more densely populated regions of America or Europe. Such being the case, the theory of invisible injury would imply that all industrial operations which result in the emission of sulphur dioxide in the atmosphere could be regarded as injurious to vegetation and be made the basis of legal action.

Prior to the investigations of the Selby Smelter Commission, 1914-1915, most of the experimental work on this subject was carried out in such a manner as to leave considerable doubt regarding the actual concentrations of sulphur dioxide gas present in the vicinity of the plants and the exact duration of each exposure. A quantity of the gas was admitted in a closed container or smoke house either by burning a weighed amount of sulphur or by adding concen-

trated sulphur dioxide from a tank or gas burette. The fumigation was conducted in a static atmosphere or without the continuous aeration of the plant which is essential if carbon dioxide assimilation and normal growth are to be maintained. Under such conditions the initial concentration is rapidly lowered by absorption of the gas by the plants, walls of the cabinet and soil. The lack of a rapid and accurate method for determining low concentrations of sulphur dioxide in air, in particular concentrations below 1 p.p.m., was a contributing factor to the uncertainty of these early experiments.

The Selby Smelter Commission (3) developed a technique for fumigating plants with sulphur dioxide which, with certain modifications, has since become recognized as the proper approach to the problem. The plants were enclosed in nearly gas-tight cabinets, the walls of which were constructed of transparent celluloid, and air was passed through continuously at sufficient velocity to produce a small excess pressure within the cabinet, the effect being that of a gentle breeze blowing over the plants. Sulphur dioxide in the desired concentrations was mixed with the air, admitted continuously, and analyses were made of the incoming and outgoing air mixtures. A study was made of the effect of various concentrations on growing barley arranged in experimental plots in the field. The experiments showed that the application of a given concentration of sulphur dioxide for a definite duration and humidity produced the same results if the treatment was applied continuously or at short intermittent intervals. The relative humidity of the atmosphere was found to be a strong determinative factor in the production of injury. It was found that 2 p.p.m. of sulphur dioxide applied continuously for four hours under average humidity conditions, or for 10 min. daily during the growing season, produced some visible injury. The effect on the ultimate yield was, however, slight. Many experiments of short duration were carried out without any appreciable effect on the yield. The Selby Commission concluded that from their investigations there was no indication of invisible injury to grain, and under certain conditions a considerable amount of visible injury did not necessarily mean a decrease in the yield of crop. Most of this work, however, was carried out with concentrations which would now be considered high in the light of fuller information in regard to sulphur dioxide conditions in industrial and smelting areas. The experiments were generally of short duration and the problem of long intermittent or continuous treatments with concentrations below 0.50 p.p.m. was not investigated.

Experiments carried out subsequently by O'Gara as discussed by Wells (13) and Swain (10), marked a further improvement in technique and added further evidence against the theory of invisible injury. The results indicated no reduction in yield unless the gas caused visible destruction of the leaf surface. In fact, O'Gara went so far as to declare that he found an actual stimulation of growth on treatment with sulphur dioxide until a point was reached where visible injury was produced.

Hill and Thomas (2) more recently studied the influence of leaf destruction by sulphur dioxide on yield of alfalfa, using short treatments with relatively high concentrations of sulphur dioxide. They found that reduction in yield was in direct proportion to the percentage of leaf area destroyed and also in proportion to the number of injurious fumigations. The reduction in yield was not, however, directly proportional to the number of leaves marked; the uninjured portions of the leaves continued to function in spite of the bleached areas. It was found that the extent of yield reduction caused by sulphur dioxide fumigation could be closely duplicated by clipping off from normal plants an amount of leaf tissue equivalent in area to that destroyed during fumigation.

Within the past few years a direct approach to the problem of invisible injury has been made by Hill and Thomas, and Katz and Ledingham (5, 6, 7) in experiments on plants grown under field conditions, while Swain and Johnson at Stanford University, and Setterstrom, Zimmerman and Crocker at the Boyce Thompson Institute, have made notable contributions to this subject in carefully controlled experiments under artificial greenhouse conditions. The investigations of Thomas and Hill (12) on the photosynthesis, respiration and yield of alfalfa in relation to sulphur dioxide show in a convincing manner that fumigations with low non-marking concentrations, even for extended periods of time, do not produce an invisible injury effect either on the protoplasm or other plant structure. In none of their experiments was the yield of crop reduced without the production of visible injury.

Swain and Johnson (11) studied the effect of exposure to sulphur dioxide concentrations for several hours daily on wheat plants grown in nutrient solutions under optimum conditions of artificial light and humidity. The fumigations were maintained below the point at which typical foliar markings are produced. They found no interference in the rate of growth, dry weight of tissue, or yield of grain.

Setterstrom, Zimmerman and Crocker (8) have recently studied the effect of low non-marking concentrations of sulphur dioxide on the yield of alfalfa grown in pots under varied experimental conditions. Water supply, nutrient supply, sulphur content of nutrient supply, and age of plants were systematically varied to enable comparison of the effects of sulphur dioxide under the several conditions, and to permit statistical analysis of the yield data. The yield of alfalfa was not decreased under any of the conditions employed. In most cases the sulphur dioxide had no significant effect, but in a few instances it brought about yield increases. It was found that deficiencies in the sulphur content of the nutrient supply could be made up by the absorption of sulphur dioxide from the air. Alfalfa grown with a deficient supply of water seemed to respond more readily to the stimulating effect of sulphur dioxide than did plants grown with an ample water supply. The response was also greater under favorable light conditions than when the light was poor.

The experiments described in this chapter were carried out by the writers at the Dominion Experimental Station at Summerland, B.C., during the course of the Trail Smelter Fumes Investigation. The experiments were designed to study, under natural field conditions, the effects of low, medium and high concentrations on the growth of barley and alfalfa, with special reference to invisible injury. Studies of the carbon dioxide assimilation and respiration of alfalfa, which have a direct bearing on this question, will be discussed in Chapter XV.

Methods

A complete description of the plots and apparatus used in this investigation has been given in Chapter VIII. In the barley plots, seeds were spaced 3 in. apart, but the plots did not always contain the same number of plants at maturity. The variations were caused by such uncontrollable factors as lack of germination, cut-worm damage, etc. In view of this fact it was considered advisable to present the yield data on the basis of the average weight per plant rather than per plot. If the plots had been sown as in ordinary farm practice and the seed not spaced, small differences caused by variations in the percentage of germination and insect damage would not have mattered, since in closely sown plots it is known that a variation within certain limits in the number of plants does not influence the weight of the plot as a whole. Where gaps occur, the space is utilized by the adjoining plants which merely increase their tillering. In the plots at Summerland, however, the plants were spaced sufficiently far apart that losses in numbers could not be replaced entirely by extra tillering. For this reason it was considered that more comparable results would be obtained if the basis of yield were the average weight per plant rather than per plot.

In the case of the alfalfa plots, however, it was possible to establish uniformity in numbers by thinning the seedlings after germination and transplanting to fill in any gaps. Each plot therefore contained 90 plants, which were well established before the fumigation experiments were started. When the plots were harvested it was usual to discard the two border rows and end plants, except where the cabinets had been maintained over the plots for long periods. In the latter case the entire plot was harvested.

Harvest Data

At harvest the alfalfa plants from the fumigated and control plots were weighed immediately for green weight, each plant being cut separately. Samples were then collected and oven-dried at 70°C. in order to determine the moisture content. From this the dry weight was calculated.

In the case of barley the harvest weight was determined when the plants had reached the proper stage of maturity. Each plant was cut separately. The number of tillers and good heads on each plant and the number of plants in

each plot were counted, and a note was made of any immature heads. The outside rows and the end plants were discarded, in order to eliminate border effects. The number of plants per plot in each series was fairly uniform, such variations as existed being due largely to uneven germination and not to the gas treatment.

The barley plants, after being weighed, were suspended in a large, well ventilated barn and dried to constant weight. The grain was then threshed in a small laboratory machine, and the number of kernels per head counted on a representative number of heads. After obtaining the weight of grain and straw, representative samples of the grain were collected and dried in an oven to constant weight. From this the total dry weight of grain was calculated, and also the dry weight of grain per plant and per head.

In 1935 this procedure in regard to the harvesting of the barley was altered somewhat, the grain weights not being reduced to oven-dry weights. The ripening of the plants in 1935 was very uniform, and it was considered unnecessary to do more than air-dry the plants until the weights were constant.

The fumigated and control plots were selected at the time of each experiment and, generally speaking, the control was situated adjacent to the fumigated plot and covered with a cabinet for the same length of time as the treated plot. This procedure was followed carefully in all the long fumigations. Consideration was given to the possible effect of shadows cast by the cabinet and equipment on one plot or the other, and at times it was found advisable to have the control plot in an adjoining row, in order to eliminate such effects. In those experiments of comparatively short duration, of only a few hours, under atmospheric humidity conditions (*i.e.*, a cabinet was not placed over the control), the plot selected for the control at the time of the experiment was an adjoining plot which after careful examination was found to be in every respect comparable to the treated plot prior to the gas treatment. As far as possible, therefore, the factor of variation in growth, between treated and control plots prior to fumigation, was eliminated by careful examination.

Owing to the fact that certain areas of the experimental field had to be left bare to provide sufficient space for the fumigation equipment, automatic sulphur dioxide and carbon dioxide analytical machines, etc., a completely random arrangement of control and treated plots was not possible. However, within these limitations the control plot for each experiment was selected at random.

Differences which developed after treatment between the fumigated and control plots could be reasonably attributed to the effect of the sulphur dioxide fumigation. However, in the analysis of the harvest data, conclusions have been based only on the results of as many experiments as possible within a series, and not on single experiments. In the following tables the yield of each fumigated plot in a given series has been compared with its corresponding control plot and calculated as a percentage of this control. The average yield for each

series, the deviations from this average, and the standard deviation and standard deviation of the mean, have been calculated in percentage. In these tables, wherever the average yield differs from 100% by a figure equal to or greater than twice the standard deviation of the mean, the results may be considered significant since the possibility of such a difference being due to chance alone is less than 1 in 20.

Experimental Results

EFFECT OF SULPHUR DIOXIDE ON YIELD OF BARLEY

Invisible Injury Series

A number of plots of barley were treated with sulphur dioxide under various conditions of exposure, over a wide range of concentrations, the fumigations not being carried beyond the point where the first symptoms of incipient injury appeared on the leaves. In other experiments the sulphur dioxide treatments were carried out with concentrations too low to cause visible markings at the indicated time of exposure. The purpose of this work was to determine whether it was possible to decrease the yield when visible symptoms were absent, or when the fumigations were not carried beyond the appearance of the first slight symptoms or markings. The results for those experiments which were carried out prior to the flowering period are summarized in Tables I and II, and in the case of treatments during the flowering period, in Tables III and IV.

Results of the 20 plots shown in Tables I and II indicate that in the absence of visible markings or when sulphur dioxide injury to the foliage is not greater than about 5%, the yield of the fumigated plants is not decreased. The mean yield per plant is 101.25%, with a standard error of 1.65%. The mean yield of straw per plant is 99.65%, while the dry weight of grain per plant is 105.45%, the standard errors being 2.08 and 2.50%, respectively. These differences are not significant. With regard to the tiller weights (Table II), similar results were obtained, the tillers being clearly not affected by the sulphur dioxide. The tiller weights and the weight of straw per tiller and grain per head of the treated plants are fully equal to those of the untreated plants within the limits of experimental error, the standard error of the mean being only 1.6 to 3.1%.

Although it is here considered advisable to present the yield data on a plant and tiller basis only, similar results were obtained for the plot weights. Compared with the controls the average weight of the fumigated plots was 101.24%. The average number of plants in the fumigated plots was 125.3, and in the controls, 126.7, for this series treated prior to the flowering stage. The average number of tillers in the fumigated plots was 876.9 and in the controls 862.5, whereas the average number of kernels per head was 20.37 for the fumigated and 20.53 for the controls. The results indicate definitely that these sulphur dioxide fumigations had no adverse influence on either the tillering or kernel production of the barley.

TABLE I
EFFECT OF SULPHUR DIOXIDE ON YIELD OF BARLEY
INVISIBLE INJURY SERIES

Fumigated plot no.	Age of plot when treated, days	Sulphur dioxide treatment		Injury to foliage, %	Fumigated plots			Adjacent control plots		
		Average conc., p.p.m.	Duration, hr.		Total wt. per plant, gm.	Wt. of straw per plant, gm.	Dry wt. of grain, gm.	Total wt. per plant, gm.	Wt. of straw per plant, gm.	Dry wt. of grain, gm.
May, 1931, sowing—first series										
I-4	40	0.50	8.0	0	30.10	18.30	10.63	28.95	17.75	10.25
I-5	37	0.75	4.2	5	25.82	15.38	9.78	26.35	16.20	9.20
I-3	39	1.00	8.0	6	27.92	17.42	9.47	26.35	16.20	9.20
D-2	26	1.20	2.25	trace	25.60	14.65	9.94	25.80	14.92	9.77
May, 1931, sowing—second series										
D-4	28	0.30	35.0	slight	16.00	9.87	5.48	16.50	10.20	5.85
D-9	27	0.60	2.25	2	13.00	8.22	4.35	12.71	8.12	4.18
D-10	26	0.90	3.20	slight	14.60	9.27	4.86	12.71	8.12	4.18
E-6	32	0.90	5.30	1	17.91	11.52	5.81	19.40	14.38	4.56
C-5	23	1.20	15.40	5	12.40	7.74	4.26	12.00	7.90	3.63
C-4	24	1.20	10.0	5	16.90	10.76	5.44	16.50	10.20	5.85
June, 1931, sowing—third series										
G-6	24	0.26	210.0	0	5.90	3.33	2.25	5.56	3.32	1.99
G-13	35	0.30	72.5	0	7.96	4.85	2.71	7.24	4.55	2.18
F-3	25	0.30	17.3	0	10.75	6.79	3.75	9.85	6.40	3.06
F-7	19	0.35	15.0	trace	6.69	4.68	1.85	6.40	4.44	1.81
I-13	27	0.75	9.0	trace	7.24	4.60	2.44	7.60	4.82	2.55
E-5	33	1.50	6.7	slight	8.88	5.48	3.10	9.08	5.78	3.05
May, 1935, sowing—fourth series										
O-9	30	0.80	22.0	4.4	15.40	8.82	6.56	19.10	11.60	7.50
M-5	22	0.70	30.0	0	13.00	7.45	5.55	12.67	7.02	5.65
N-4	44	0.78	37.5	0	12.40	7.64	4.80	11.72	7.46	4.26
{ O-3	22	0.88	4.0	0						
{ O-3	46	1.95	17.0	7	12.40	8.08	4.30	13.04	8.30	4.74
Mean yield calculated as percentage of control					101.25	99.65	105.45			
Standard deviation per cent					7.40	9.35	11.20			
Standard deviation of mean, per cent					1.65	2.08	2.50			

TABLE II

EFFECT OF SULPHUR DIOXIDE ON YIELD OF BARLEY
INVISIBLE INJURY SERIES

YIELD OF BARLEY AND ALFALFA

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Fumigated plot no.	Age of plot when treated, days	Sulphur dioxide treatment		Injury to foliage, %	Fumigated plots			Adjacent control plots		
		Average conc., p.p.m.	Duration, hr.		Total wt. per tiller, gm.	Total wt. of straw, gm.	Dry wt. of grain per head, gm.	Total wt. per tiller, gm.	Total wt. of straw, gm.	Dry wt. of grain per head, gm.
May, 1931, sowing—first series										
I-4	40	0.50	8.0	0	2.28	1.38	0.81	2.20	1.35	0.785
I-5	37	0.75	4.2	5	2.09	1.25	0.80	2.15	1.32	0.757
I-3	39	1.00	8.0	6	2.02	1.26	0.69	2.15	1.32	0.757
D-2	26	1.20	2.25	trace	1.85	1.06	0.73	2.07	1.19	0.780
May, 1931, sowing—second series										
D-4	28	0.30	35.0	slight	1.68	1.03	0.585	1.82	1.12	0.650
D-9	27	0.60	2.25	2	1.62	1.02	0.545	1.69	1.08	0.565
D-10	26	0.90	3.20	slight	1.57	1.05	0.53	1.69	1.08	0.565
E-6	32	0.90	5.30	1	2.34	1.51	0.76	2.34	1.73	0.550
C-5	23	1.20	15.40	5	1.72	1.07	0.58	1.42	0.94	0.440
C-4	24	1.20	10.0	5	1.82	1.16	0.59	1.82	1.12	0.650
June, 1931, sowing—third series										
G-6	24	0.26	210.0	0	1.33	0.75	0.55	1.34	0.80	0.510
G-13	35	0.30	72.5	0	1.41	0.86	0.51	1.40	0.88	0.505
F-3	25	0.30	17.3	0	1.74	1.10	0.61	1.74	1.13	0.550
F-7	19	0.35	15.0	trace	1.61	1.12	0.47	1.48	1.03	0.450
I-13	27	0.75	9.0	trace	1.57	0.97	0.53	1.57	0.99	0.570
E-5	33	1.50	6.7	slight	1.62	1.00	0.57	1.65	1.05	0.560
May, 1935, sowing—fourth series										
O-9	30	0.80	22.0	4.4	2.23	1.28	1.09	2.50	1.52	1.23
M-5	22	0.70	30.0	0	2.18	1.25	1.07	2.27	1.26	1.20
N-4	44	0.78	37.5	0	1.68	1.06	0.90	1.56	0.99	0.73
{ O-3	22	0.88	4.0	0						
{ O-3	46	1.95	17.0	7	1.62	1.05	0.84	1.67	1.06	0.86
Mean yield calculated as percentage of control					99.05	97.50	102.60			
Standard deviation per cent					7.35	7.23	14.0			
Standard deviation of mean, per cent					1.64	1.61	3.13			

In the case of those experiments carried out during the flowering period of barley, shown in Table III, the fumigations being discontinued at the first sign of incipient injury to the foliage, the yield per plant and the weight of straw and grain per plant are somewhat greater for the fumigated than the control, the increase in weight being of the order of about twice the standard error or less.

From the data in Table IV no appreciable differences are found in the tiller weights between the fumigated and controls. With regard to the plot weights the same trend is shown, the average weight of all the fumigated plots being 99.79% of the controls. The average number of plants in the fumigated plots was in this case 106, compared with 110 in the controls. Because of the slightly smaller number of plants in the fumigated plots, the number of tillers per plot was slightly greater than in the controls, the average number of tillers for the fumigated plots being 1033 and for the controls 1024.8, or on a percentage basis, 100.8. The average number of kernels for the fumigated plots was 22.8 and for the controls 22.73. Although the fumigated plots have been compared with the adjacent controls the results are not appreciably different if the yield of fumigated plot is compared with the average of all the control plots. The standard error in the latter case is somewhat greater. If the yield data of the plots fumigated prior to the flowering period and those fumigated during the flowering period are considered as comprising an invisible injury series of 29 plots, then the mean weight per plant expressed as a percentage of the adjacent control is 102.0%, the weight of straw, 100.7%, the weight of grain, 105.5%, and the standard errors are 1.31, 1.65 and 1.85, respectively. On the same basis the weight per tiller of the fumigated plants is 99.6%, the straw per tiller, 98.0%, and the grain per head, 102.4%, with standard errors of 1.38, 1.33 and 2.36, respectively.

EFFECT OF TWENTY PER CENT LEAF DESTRUCTION PRIOR TO FLOWERING

A further series of fumigations was carried out prior to the flowering period of the barley, under more severe conditions, the average leaf injury being 20.3%, with the minimum 10% and the maximum 31%. The treatments cover a considerable range in concentration from 0.78 to 2.0 p.p.m. A small reduction in yield is evident in this series. (Tables V and VI). The average weight per plant, calculated in percentage of the adjacent control is 93.3, weight of straw, 92.0, and the weight of grain, 95.5%, with standard errors of 2.39, 2.77 and 2.83, respectively. The sulphur dioxide effect is greater on the straw than on the grain. In fact, the decrease in the grain weight is scarcely significant. The relatively greater effect on the straw is also indicated in the tiller weights (Table VI).

The fumigated plants show a marked ability to recover from the effects of injurious fumigations. Not only does sulphur dioxide have no detrimental effect on yield until after symptoms of injury appear on the leaves, but from this point onward the growth of the plant is retarded and the yield decreased only

TABLE III
EFFECT OF SULPHUR DIOXIDE ON YIELD OF BARLEY
INVISIBLE INJURY SERIES
(Fumigations carried out during the flowering period.)

Fumigated plot no.	Age of plot when treated, days	Sulphur dioxide treatment		Injury to foliage, %	Fumigated plots			Adjacent control plots		
		Average conc., p.p.m.	Duration, hr.		Total wt. per plant, gm.	Wt. of straw per plant, gm.	Dry wt. of grain, gm.	Total wt. per plant, gm.	Wt. of straw per plant, gm.	Dry wt. of grain, gm.
May, 1931, sowing—fifth series										
M-2	55	0.50	23.5	slight	24.75	16.02	7.75	23.55	14.75	7.64
N-3	56	0.75	23.75	very slight	22.39	14.60	7.75	21.65	13.30	7.64
M-6	54	0.85	9.0	5	17.82	11.32	5.80	17.93	12.35	5.13
N-5	54	0.95	9.0	very slight	20.30	13.45	6.18	19.02	12.50	6.02
J-4	53	1.00	29.25	slight	23.20	14.40	7.96	23.90	14.70	8.30
J-6	53	1.00	9.0	slight	18.35	11.00	6.39	15.68	9.70	5.60
J-7	51	1.50	7.25	slight	15.11	10.35	4.34	13.84	9.68	3.70
N-1	57	1.50	7.0	very slight	21.98	13.45	7.54	22.35	13.92	7.57
M-4	55	2.00	7.0	slight	23.78	13.69	9.26	23.75	14.29	8.70
Mean yield calculated as percentage of control					104.00	103.00	105.80			
Standard deviation per cent					6.42	7.59	7.20			
Standard deviation of mean, per cent					2.14	2.53	2.40			

TABLE IV
EFFECT OF SULPHUR DIOXIDE ON YIELD OF BARLEY
INVISIBLE INJURY SERIES
(Fumigations carried out during the flowering period.)

Fumigated plot no.	Age of plot when treated, days	Sulphur dioxide treatment		Injury to foliage, %	Fumigated plots			Adjacent control plots		
		Average conc., p.p.m.	Duration, hr.		Total wt. per tiller, gm.	Total wt. of straw, gm.	Dry wt. of grain per head, gm.	Total wt. per tiller, gm.	Total wt. of straw, gm.	Dry wt. of grain per head, gm.
May, 1931, sowing—fifth series										
M-2	55	0.50	23.5	slight	2.30	1.42	0.685	2.26	1.42	0.735
N-3	56	0.75	23.75	very slight	2.03	1.32	0.795	2.13	1.32	0.755
M-6	54	0.85	9.0	5	1.90	1.21	0.620	1.76	1.21	0.510
N-5	54	0.95	9.0	very slight	2.17	1.44	0.665	1.92	1.26	0.610
J-4	53	1.00	29.25	slight	1.91	1.18	0.655	2.09	1.28	0.730
J-6	53	1.00	9.0	slight	1.91	1.15	0.675	1.92	1.19	0.690
J-7	51	1.50	7.25	slight	1.71	1.17	0.440	1.62	1.13	0.430
N-1	57	1.50	7.0	very slight	2.00	1.22	0.690	2.23	1.39	0.755
M-4	55	2.00	7.0	slight	2.10	1.22	0.825	2.10	1.27	0.770
Mean yield calculated as percentage of control					100.90	99.00	102.00			
Standard deviation per cent					7.70	7.45	10.00			
Standard deviation of mean, per cent					2.56	2.49	3.33			

to the extent that the plant is unable to replace the damaged leaf tissue under normal growing conditions. If the markings cover only a small percentage of the total leaf area, the barley is capable of replacing this loss. On the other hand, if the leaf injury is greater than about 10%, a reduction in the weight of straw usually takes place, but not necessarily in the weight of grain.

EFFECT OF SEVERE FUMIGATION DURING FLOWERING PERIOD

The results in Tables VII and VIII indicate the effect on yield of a series of severe sulphur dioxide treatments during the flowering period. Most of the fumigations were carried out with concentrations between 1.0 and 5.0 p.p.m., since it was found that barley at this stage of its development is considerably more resistant to sulphur dioxide than during its early growth. During the flower and milk stage the lower leaves of the plant show a considerable reduction in their physiological activity, while the top leaves have declined from their maximum assimilating capacity. There is also a decline in the rate of vegetative growth. These factors are responsible for the lessened susceptibility of the plant to sulphur dioxide.

The sulphur dioxide fumigations produced, in addition to injury to the foliage, straw-yellow discolorations on the tips of the awns and, in some cases, a bleaching of the glumes and false flowers. The harvest data indicate that in spite of these severe treatments with high concentrations of gas there was no reduction in the weight of straw. Since most of the vegetative growth has been completed by the time the barley has attained the flower stage, a reduction in the weight of straw would not be expected, even in the case of the heavily injured plots, unless the discolored leaves were shed. This was not observed to take place to any appreciable extent. On the other hand, the yield of grain was considerably reduced. This result is shown not only in the plant weights but also in the tiller weights, there being a definite reduction in the weight per tiller and the weight of grain per head.

The average number of plants in the fumigated plots of this series was only slightly less than that in the controls. The plot weights show the same effect on yield as the plant weights, *i.e.*, no reduction in straw, but a reduction of about 15% in the grain. There was no indication of a decrease in the number of tillers per plant and this result is to be expected since the tiller development had been practically completed by the time the plants were fumigated. A count of the number of kernels per head indicated no substantial difference in this respect between the fumigated and control plants. The decrease in yield of grain, therefore, is the result of a reduction in the weight of the kernels.

Hitherto the results of the sulphur dioxide fumigations on barley have been considered only in connection with leaf injury. It is of interest, therefore, to

TABLE V
EFFECT ON YIELD OF TEN TO THIRTY PER CENT LEAF INJURY TO BARLEY

Fumigated plot no.	Age of plot when treated, days	Sulphur dioxide treatment		Injury to foliage, %	Fumigated plots			Adjacent control plots		
		Average conc., p.p.m.	Duration, hr.		Total wt. per plant, gm.	Wt. of straw per plant, gm.	Dry wt. of grain, gm.	Total wt. per plant, gm.	Wt. of straw per plant, gm.	Dry wt. of grain, gm.
May, 1931, sowing										
D-6	30	0.95	2.0	20	11.40	7.57	3.47	12.60	8.30	3.84
D-8	20	1.00	32.6	30	12.50	8.44	3.66	12.75	8.05	4.18
E-10	31	1.20	4.5	30	15.65	11.11	4.07	19.40	14.33	4.56
C-7	22	1.20	23.2	15	13.00	7.98	4.61	14.70	9.38	4.91
May, 1931, sowing										
C-2	26	1.20	3.4	30	31.00	17.72	11.71	39.90	24.84	13.58
June, 1931, sowing										
I-11	28	1.00	4.5	10	6.19	4.26	1.76	6.16	4.50	1.47
F-6	21	1.00	8.0	10	8.65	5.53	2.90	8.95	5.93	2.85
I-9	27	1.50	8.5	20	6.20	4.89	1.18	6.15	4.68	1.32
G-11	37	2.00	21.7	18	5.14	3.44	1.43	6.43	4.34	1.78
May, 1935, sowing										
M-3	42	0.78	46.0	26	12.94	7.62	5.32	12.35	7.86	4.49
N-2	43	0.80	33.0	27	12.15	7.95	4.20	11.72	7.46	4.26
N-6	43	0.86	28.0	31	14.80	8.45	6.35	17.98	10.75	7.23
P-8	30	0.90	48.0	14	17.65	9.80	7.80	17.91	10.40	7.51
P-2	22	0.91	25.0	16	14.68	8.80	5.88	14.40	8.50	5.90
O-11	32	1.22	23.5	12	14.10	8.00	6.10	13.20	7.40	5.80
P-10	32	1.22	23.5	14	16.37	9.73	6.64	20.13	11.68	8.45
P-4	24	1.48	16.5	23	13.36	7.85	5.51	14.40	8.50	5.90
Mean yield calculated as percentage of control					93.30	92.00	95.50			
Standard deviation per cent					9.85	11.40	11.67			
Standard deviation of mean, per cent					2.39	2.77	2.83			

TABLE VI
EFFECT ON YIELD OF TEN TO THIRTY PER CENT LEAF INJURY TO BARLEY

Fumigated plot no.	Age of plot when treated, days	Sulphur dioxide treatment		Injury to foliage, %	Fumigated plots			Adjacent control plots		
		Average conc., p.p.m.	Duration, hr.		Total wt. per tiller, gm.	Total wt. of straw, gm.	Dry wt. of grain per head, gm.	Total wt. per tiller, gm.	Total wt. of straw, gm.	Dry wt. of grain per head, gm.
May, 1931, sowing										
D-6	30	0.95	2.0	20	1.54	1.03	0.480	1.60	1.06	0.500
C-8	20	1.00	32.6	30	1.64	1.10	0.485	1.70	1.08	0.563
E-10	31	1.20	4.5	30	1.69	1.20	0.440	2.34	1.75	0.550
C-7	22	1.20	23.2	15	1.61	0.99	0.575	1.79	1.14	0.605
May, 1931, sowing										
C-2	26	1.20	3.4	30	2.05	1.17	0.790	2.27	1.41	0.800
June, 1931, sowing										
I-11	28	1.00	4.5	10	1.37	0.94	0.460	1.36	0.99	0.400
F-6	21	1.00	8.0	10	1.82	1.17	0.650	1.62	1.07	0.525
I-9	27	1.50	8.5	20	1.23	0.97	0.330	1.53	1.16	0.410
G-11	37	2.00	21.7	18	1.11	0.74	0.400	1.17	0.78	0.400
May, 1935, sowing										
M-3	42	0.78	46.0	26	1.85	1.09	0.950	1.71	1.09	0.930
N-2	43	0.80	33.0	27	1.59	1.04	0.600	1.56	0.99	0.730
N-6	43	0.86	28.0	31	1.83	1.04	0.990	1.66	1.20	1.020
P-8	30	0.90	48.0	14	1.99	1.03	1.670	1.87	1.09	1.360
P-2	22	0.91	25.0	16	1.84	1.11	1.220	1.93	1.14	1.230
O-11	32	1.22	23.5	12	1.96	1.11	1.090	1.90	1.05	1.030
P-10	32	1.22	23.5	14	1.90	1.06	1.440	2.28	1.33	1.440
P-4	24	1.48	16.5	23	1.77	1.04	1.100	1.93	1.14	1.230
Mean yield calculated as percentage of control					97.10	93.00	98.50			
Standard deviation per cent					11.02	10.46	13.30			
Standard deviation of mean, per cent					2.68	2.54	3.23			

TABLE VII
EFFECT OF SEVERE SULPHUR DIOXIDE TREATMENT DURING FLOWERING PERIOD ON YIELD OF BARLEY

Fumigated plot no.	Age of plot when treated, days	Sulphur dioxide treatment		Injury to foliage, %	Fumigated plots			Adjacent control plots		
		Average conc., p.p.m.	Duration, hr.		Total wt. per plant, gm.	Wt. of straw per plant, gm.	Dry wt. of grain, gm.	Total wt. per plant, gm.	Wt. of straw per plant, gm.	Dry wt. of grain, gm.
May, 1931, sowing										
J-2	54	2.00	10.33	15	25.80	16.25	8.65	28.95	17.75	10.25
June, 1931, sowing										
J-12	55	3.00	22.70	10	8.31	6.36	1.76	7.60	4.82	2.55
J-10	56	5.00	22.80	35	5.24	3.91	1.22	5.98	4.47	1.37
May, 1935, sowing										
M-13	57	0.88	40.50	28	12.71	7.71	5.00	11.90	6.85	5.05
O-13	57	0.88	88.50	14* } 33† }	10.00	6.43	3.57	13.20	7.40	5.80
S-2	59	1.00	46.00	35	11.56	7.15	4.41	11.11	6.64	4.47
N-12	57	1.44	40.50	59	12.67	8.17	4.50	10.23	5.65	4.58
N-10	59	1.70	46.00	69	11.07	7.00	4.07	11.21	6.54	4.67
N-8	46	1.93	12.00	48	12.74	9.24	3.50	16.46	9.65	6.81
{ P-12	57	2.07	24.00	59	11.10	6.65	4.45	13.54	7.60	5.94
Mean yield calculated as percentage of control -----										
Standard deviation per cent -----										
Standard deviation of mean, per cent -----										

* Leaves

† Awns

TABLE VIII
EFFECT OF SEVERE SULPHUR DIOXIDE TREATMENT DURING FLOWERING PERIOD ON YIELD OF BARLEY.

EFFECT OF SEVERE SULPHUR DIOXIDE INJURY

Fumigated plot no.	Age of plot when treated, days	Sulphur dioxide treatment		Injury to foliage, %	Fumigated plots			Adjacent control plots					
		Average conc., p.p.m.	Duration, hr.		Total wt. per tiller, gm.	Total wt. of straw, gm.	Dry wt. of grain per head, gm.	Total wt. per tiller, gm.	Total wt. of straw, gm.	Dry wt. of grain per head, gm.			
May, 1931, sowing													
J-2	54	2.00	10.33	15	1.90	1.20	0.635	1.35	2.20	0.785			
June, 1931, sowing													
J-12	55	3.00	22.70	10	1.35	1.02	0.35	0.99	1.57	0.570			
J-10	56	5.00	22.80	35	1.13	0.84	0.35	1.07	1.43	0.410			
May, 1935, sowing													
M-13	57	0.88	40.50	28 14* } 33† } 35 59 69 48 59	1.84	1.12	1.23	1.15	1.99	1.28			
O-13	57	0.88	88.50		1.50	0.96	0.84	1.05	1.90	1.03			
S-2	59	1.00	46.00		1.61	1.00	0.90	0.88	1.47	0.85			
N-12	57	1.44	40.50		1.88	1.21	0.89	1.01	1.82	0.97			
N-10	59	1.70	46.00		1.94	1.22	0.90	1.25	2.14	0.99			
N-8	46	1.93	12.00	1.60	1.12	0.81	1.21	2.06	1.06				
{ P-12	57	2.07	24.00	59	1.67	1.00	1.20	1.11	1.97	1.32			
{ P-12		5.80	14.00										
Mean yield calculated as percentage of control											88.80	97.30	86.10
Standard deviation per cent											10.35	12.38	12.26
Standard deviation of mean, per cent				3.23	3.86	3.83							

* Leaves

† Awns

consider the summary shown in Table IX, where the results are compared not only on the basis of leaf destruction but also of increasing concentration of gas and time of exposure. The data indicate that with the average leaf destruction less than 5% there is no effect on the yield when barley is treated with an average concentration of 0.30 p.p.m. for an average duration of 70 hr., 0.65 to 0.92 p.p.m. for about 14 hr. and 1.33 p.p.m. for 10.3 hr.

The yield of 29 fumigated plots where the average treatment was 0.936 p.p.m. for 22.7 hr. resulting in a leaf destruction of 1.4%, was not reduced in the slightest degree, both the plant weights and tiller weights being similar to the controls. When expressed as a percentage of the control, the weight per plant is $102\% \pm 1.31$ and the weight of grain $105.5\% \pm 1.85$. The increase in grain weight is statistically significant.

THE EFFECT OF FUMIGATIONS SIMILAR TO THOSE FOUND IN A SMELTER AREA

An attempt was made to apply experimentally to a crop at Summerland a series of fumigations as nearly as possible identical with those occurring in May and June 1931 at the Stroh farm plots in the Northport area, about 15 miles south of Trail. The sulphur dioxide and meteorological records taken at the Stroh farm were sent every few days to Summerland, and similar conditions of fumigation were then imposed on the barley crop set aside for this purpose. In order to maintain temperature and humidity factors as nearly comparable as possible, several fumigations relayed from the Stroh farm were not repeated until some later date when weather conditions at Summerland chanced to be more favorable. Owing to the effect of the fumigation cabinet, temperatures were somewhat higher at Summerland than those recorded at the Stroh farm, and for this reason the humidity could not be duplicated as closely as one could wish. The data for the experimental fumigations, which covered a period of about forty days, will be found in Table XII, Chapter XI.

Plots 12 ft. square were set aside for the work. The seed was sown by hand in rows one foot apart and there were eleven such rows to a plot. The seeds in each row were spaced about 3 in. apart. Seeding took place on May 20, and the plants appeared above ground on May 26. The weather was very warm and dry, but the young seedlings grew very rapidly as they were irrigated adequately.

Plot B-5 was selected for fumigation work and B-4 as a cabinet control. The cabinets were put in place on May 27, when the barley plants were about 2 in. high and still in the seed leaf stage. The first treatment with sulphur dioxide was applied on May 29. B-4, the control plot, received the same treatment in every respect but for the sulphur dioxide gas. The other plots in this range were used as outside controls.

The effect of two days under cabinet conditions before the first fumigation was applied was evident in an increased height growth. The average height

of the plants under the cabinets was 3.75 in. on May 29, an average of 0.5 in. higher than that of the plants in the outside control plots.

During the period May 29 to July 8, the barley was subjected to 23 fumigations, the total duration of these being 213 hr. and 50 min., and the average concentration, 0.27 p.p.m. The maximum concentration was 1.05 p.p.m. In the same period the experimental plots at the Stroh farm in the Northport area were exposed for 249 hr. and 40 min. to an average concentration of 0.21 p.p.m. and a maximum of 1.25 p.p.m. (trace values below 0.04 p.p.m. being omitted). This includes, however, about 34 hr. of low concentrations between 0.04 and 0.06 p.p.m. which were neglected in the attempt to duplicate the conditions of the Stroh farm at Summerland. Actually the Stroh farm gas concentrations which were repeated at Summerland on Plot B-5 may be represented by about 215 hr. at an average concentration of 0.24 p.p.m.

There were no symptoms of sulphur dioxide injury on the barley during the first 15 fumigations. The longest of these fumigations was of 19 hours' duration, with an average concentration of 0.30 p.p.m. Nearly all the other treatments were of about four to five hours' duration in the morning, from about 8.00 or 9.00 a.m. onward. In most of these treatments the concentrations fluctuated between the values of 0.10 to about 0.60 p.p.m.

During June 17 to 19 the plants were treated with gas continuously for 47 hr. and 45 min. at an average concentration of 0.244 p.p.m. and a maximum of 0.66 p.p.m. in duplication of a similar gas visitation which had occurred at the Stroh farm a few days previously. Throughout this fumigation the humidity was quite high, the minimum being not lower than 54%, and the maximum, 97%. The first sulphur dioxide symptoms noted on June 19 were slight in character and consisted of tip markings on the upper 5th, 6th and 7th leaves on about 25% of the plants. These first symptoms occurred, therefore, after 124 hr. of intermittent fumigation, with an average concentration of 0.29 p.p.m. On June 21 the plants were treated with sulphur dioxide from 9.20 a.m. to 12.40 p.m., without injury resulting therefrom, although the concentrations ranged from 0.18 to 0.76 p.p.m., the humidity being 50 to 58%.

Following this the plants were again treated for 15 hr., from 7.30 p.m. June 21, until 10.30 a.m., June 22, at an average concentration of 0.18 p.p.m., with a maximum of 0.64 p.p.m., the relative humidity being 80 to 97% most of the time. This caused additional markings to appear on the tips of the younger leaves, the marked tips being now found on about half the total number of plants in the plot.

Additional symptoms of injury were found on the 28th, following two more fumigations and also on July 2, after a long fumigation of 32 hours' duration, the concentrations ranging from 0.03 to 0.79 p.p.m., with the average 0.20 p.p.m. The injury to the leaf area of the plot as a whole during this series of fumigations was about 15%, chlorotic or acute markings being found on almost

every plant. Since all this injury had occurred during the last two weeks of sulphur dioxide treatment, the earlier markings were still visible on the upper leaves. The injured areas on the leaves extended in many instances from 1 to 3 in. back from the tips. There also appeared to be more senescent leaves on the fumigated than on the control plot.

The first appearance of the awns in the plants under the cabinets (Plots B-4 and B-5) was noted on July 3, and a day or two later in the outside plots. The plants under the cabinets were still noticeably taller than those outside, although this difference was not as pronounced as it was during the first few weeks. The fumigated plot appeared to be more uneven in growth, and the lower leaves of the plants were aging more rapidly than the leaves under the control cabinet.

The harvest data on the fumigated plot, B-5, its cabinet control, B-4, and the outside plots are shown in Table X. The number of plants in the different plots in this series showed some variation which was due largely to the uneven germination, and has no reference to the gas treatment. The average number in the outside plots was 364, in the cabinet control, 397, and in the fumigated plot, 389.

The number of tillers was found to be almost equal to the number of heads in a given plot, the slight difference being due mostly to accident in handling, and to the effects of wind and ravages of birds, etc. The number of heads per plot, however, showed some variation. There were 3,010 heads on an average in the outside controls, 2,785 heads in the cabinet control B-4, and 2,401 heads in the fumigated plot B-5. The difference in the average number of heads or tillers in the outside controls compared with the cabinet control was probably due to the variation in the number of plants, since with a somewhat larger number of plants Plot B-4, the cabinet control, would be expected to have a smaller number of tillers per plant. However, the cabinet factor was distinctly noticeable in the taller growth exhibited by the plants under cabinets. Thus on June 8 the average height of the plants in the outside plots was 8.1 in., whereas in the cabinet it was 11.5 in. Similarly on June 20 the average height for the outside controls was 16.8 in., while the plants in the control cabinet measured 22.4 in. and those in the fumigation cabinet 21.6 in. The first appearance of the awns on the plants under the cabinets was noted about a day or two earlier than on those in the outside controls. However, the main difference between the plants in the control cabinet and those growing outside was in the taller growth rather than in the rapidity of development.

With regard to the effect of the cabinet on the plot yields, it is seen from Table X that there is scarcely any difference in total weight, so that the increase in height growth did not result in a corresponding increase in yield. The average weight per plant is lower in the case of the cabinet control, but this can be accounted for by the fact that the number of plants in Plot B-4 was 9% greater than that in the outside controls. The tiller weights of Plot B-4 are greater than those of the outside controls; this is to be expected because of the smaller number of tillers.

TABLE X

YIELD OF BARLEY AFTER INTERMITTENT TREATMENT FOR 40 DAYS WITH AVERAGE CONCENTRATION OF 0.27 P.P.M. FOR 214 HR.
23 FUMIGATIONS, COMMENCING WHEN PLANTS WERE NINE DAYS OLD

Plot no.	No. of plants	No. of tillers	No. of heads	*Plot weights			Plant weights			Tiller weights			No. of heads per plant	No. of kernels per head
				Total weight, gm.	Wt. of straw, gm.	Dry wt. of grain, gm.	Total weight, gm.	Wt. of straw, gm.	Dry wt. of grain, gm.	Total weight, gm.	Wt. of straw, gm.	Dry wt. of grain, gm.		
Outside controls B-1 B-2 B-3	387	3342	3339	5691	3512	1969	14.75	9.10	5.09	1.70	1.05	0.59	8.60	21.92
	358	3000	2993	5403	3710	1557	15.10	10.32	4.35	1.80	1.23	0.52	8.35	22.47
	347	2700	2698	4728	3096	1465	13.62	8.92	4.22	1.75	1.15	0.543	7.77	21.35
Average	364	3014	3010	5274	3439	1664	14.50	9.45	4.57	1.75	1.14	0.554	8.26	21.90
Cabinet control B-4	397	2808	2785	5334	3427	1734	13.42	8.64	4.36	1.90	1.22	0.623	7.00	22.00
Fumigated B-5	389	2440	2401	4503	2614	1698	11.58	6.73	4.36	1.85	1.07	0.707	6.17	21.70
B-4 calculated as per cent of average outside control				100.8	99.7	104	92.50	91.40	95.40	108.40	107.00	112.50	84.70	100.50
B-5 calculate as per cent of average outside control				85.4	76.1	102	79.70	71.20	95.40	105.80	93.80	128.00	74.50	99.00
B-5 calculated as per cent of the cabinet control				84.5	76.2	97.9	86.20	78.00	100.00	97.40	87.70	113.50	89.70	98.50

* Plot weights in each case are computed on a basis of eight rows or 88 sq. ft.

On the whole, therefore, it is doubtful whether the yield of barley has been affected to any extent by cabinet conditions imposed on the plants. With regard to the effect of the sulphur dioxide treatments, the yield of the fumigated plot appears to have been noticeably reduced as regards the weight of straw. The grain weight, however, has been unaffected. This is equally true for the plot weights, plant weights and tiller weights. There also appears to be a reduction in the number of heads per plant in the case of the fumigated plot, but the number of kernels per head has not been affected. Since the number of plants in the fumigated plot was only about 2% less than in the cabinet control these differences are undoubtedly significant.

EFFECT OF SULPHUR DIOXIDE ON YIELD OF ALFALFA

Invisible Injury Series

The question of a possible decrease in yield or invisible injury effect after treatment with low concentrations of sulphur dioxide was studied intensively with alfalfa as the plant material. It was found that alfalfa is somewhat more sensitive to sulphur dioxide than barley, although both plants are among the most susceptible species. However, alfalfa, after the primary leaves have unfolded, shows practically uniform susceptibility throughout its entire growth period, while in the case of barley the susceptibility is greatest during the early growth stage and decreases quite rapidly after the flower stage with advancing maturity.

With regard to the effect of average concentrations of 0.10 to 0.30 p.p.m. on yield of alfalfa, 16 plots were fumigated with concentrations in this range, the sulphur dioxide treatments being continued until the first symptoms of sulphur dioxide injury appeared on the leaves or, in the case of the lowest concentrations, until the plants had reached the flowering stage and were ready to be harvested. The yield data are shown in Table XI. As mentioned previously, the number of plants in each alfalfa plot was exactly 90. In most instances, particularly in the shorter experiments, the number of plants harvested was 52, the remainder, consisting of the border rows and the end plants, being discarded. However, in the case of the long experiments where the plants were grown under cabinets for relatively long periods and there was no noticeable border effect, the entire treated plot and its control were harvested.

The results in Table XI indicate that plants fumigated with concentrations of 0.10 to 0.30 p.p.m. are not reduced in yield when the fumigations do not result in a measurable amount of leaf destruction, or when the gas treatment is not carried beyond the first slight symptoms of visible injury. The mean yield of the plots in Table XI is $97.4\% \pm 2.62$ for the green weight and $100.5\% \pm 2.14$ for the dry weight. If those plots which showed an appreciable number of marked leaves are excluded from this table, then the mean yield of the remaining 12 plots is equal to $100.4\% \pm 2.29$ green weight and $103.0\% \pm 2.16$ dry weight.

TABLE XI
EFFECT OF SULPHUR DIOXIDE TREATMENT WITH CONCENTRATIONS OF 0.10 TO 0.30 P.P.M. ON YIELD OF ALFALFA

Plot	Sulphur dioxide treatment		Leaves marked by SO ₂ , %	No. of plants	Yield			
	Average conc., p.p.m.	Duration, hr.			Fumigated plots		Control plots	
					Green wt., gm.	Dry wt., gm.	Green wt., gm.	Dry wt., gm.
I-11	0.10	196.5	†	90	7,876	1,605	8,615	1,480
H-15	0.10	128.5	0	52	4,619	885	3,986	754
C-11	0.10	504.0	0	90	6,345	1,067	6,766	1,087
G-12	0.11	602.0	0	90	6,656	1,172	6,757	1,047
G-8	0.12	240.0	chlorotic	52	2,375	428	3,275	508
I-12	0.14	525.0	3	52	5,110	833	5,410	832
C-10	0.15	167.0	0	52	3,650	657	3,960	705
G-16	0.16	562.0	0	90	5,764	974	5,600	918
H-11	0.17	60.0	0	52	4,720	761	4,870	809
B-4	0.17	95.0	11	90	4,740	967	4,873	981
A-5	0.17	112.5	15	90	3,730	817	4,533	919
D-12	0.20	88.0	0	52	4,245	713	4,398	739
C-11	0.20	87.5	0	52	4,815	901	4,550	832
H-5	0.24	160.0	15	90	6,349	1,080	6,230	1,085
B-6	0.28	87.25	†	90	6,380	1,175	5,675	1,140
H-9	0.30	66.5	†	52	2,600	447	2,490	458
Mean yield calculated as percentage of adjacent control					97.4	100.5		
Standard deviation, %					10.5	8.56		
Standard deviation of mean, %					2.62	2.14		
Invisible Injuries Series I—No appreciable leaf injury.								
Statistics of yield data, excluding Plots G-8, B-4, A-5 and H-5, which showed appreciable leaf markings, from above Table								
Mean yield calculated as percentage of adjacent control					100.4	103.0		
Standard deviation, %					7.96	7.51		
Standard deviation of mean, %					2.29	2.16		

† Less than 1% of leaves marked by sulphur dioxide.

TABLE XII
EFFECT OF SULPHUR DIOXIDE ON YIELD OF ALFALFA

Fumigated plot	Sulphur dioxide treatment		No. of plants	Yield			
	Average conc., p.p.m.	Duration, hr.		Fumigated plots		Control plots	
				Green wt., gm.	Dry wt., gm.	Green wt., gm.	Dry wt., gm.
Invisible Injury Series II—No appreciable leaf injury							
B-15	0.26	12.0	52	4,200	853	4,230	889
D-7	0.36	8.0	52	3,040	633	2,720	614
D-13	0.37 } 0.67 }	9.5 } 7.0 }	52	4,130	720	4,060	752
D-13	0.44	4.0	52	4,720	959	4,300	929
B-10	0.50	10.0	52	2,925	585	2,598	520
D-11	0.56	16.0	52	4,320	722	3,650	673
C-16	0.55	4.0	52	4,580	894	4,800	940
C-16	0.61	4.67	52	4,150	744	4,510	772
C-14	0.61	4.0	52	4,860	778	4,510	772
H-11	0.64	8.0	52	5,070	923	4,890	998
I-10	0.66	8.0	52	5,890	1,020	5,850	1,007
I-14	0.66	8.0	52	5,780	948	5,930	1,073
D-15	0.76	4.0	52	4,920	994	4,980	991
C-17	0.80	7.5	52	3,875	698	3,828	743
D-11	0.81	13.75	52	4,200	895	4,070	911
D-10	0.86	7.5	52	4,550	787	4,355	778
C-8	0.87	8.0	52	3,180	797	3,130	667
A-11	0.87	17.0	52	3,060	612	3,095	619
I-12	0.96	4.0	52	6,460	975	6,230	1,071
H-9	0.94	4.0	52	3,650	759	4,170	846
D-9	0.99	8.0	52	2,780	586	2,720	614
C-12	1.00	4.25	52	4,720	779	4,510	772
D-15	1.01	4.0	52	4,270	812	4,235	742
D-17	1.08	4.0	52	4,870	998	4,855	966
D-16	1.15	5.25	52	3,730	701	3,970	724
F-13	1.38	7.25	52	4,830	874	4,780	856
C-4	1.47	4.0	52	4,630	977	4,300	915
C-8	1.85	7.25	52	4,030	875	3,755	892
F-17	2.51	4.0	52	5,030	925	4,630	852
Mean yield calculated as percentage of adjacent control				102.6	100.2		
Standard deviation, %				6.43	6.96		
Standard deviation of mean, %				1.19	1.29		

Among these plots are four which were treated for 500 to 600 hr. continuously with average concentrations of 0.10 to 0.16 p.p.m. and four more fumigated with concentrations of 0.20 to 0.30 p.p.m. for 66.5 to 80 hr., continuously. These experiments clearly show that even under such conditions of prolonged exposure there is no evidence of an invisible injury effect on the yield.

Another series of experiments was carried out on a considerable number of plots with sulphur dioxide treatments of relatively shorter duration, but with higher concentrations of gas than those shown in Table XI. The yield and fumigation data have been summarized in Table XII. The lowest concentration used in this series was 0.26 p.p.m. and the highest 2.51 p.p.m., while the duration of the sulphur dioxide treatments varied from 4 to 17 hr., the object in these experiments being to avoid injury to the leaf tissue as far as possible. In this second invisible injury series, none of the plots shown in Table XII sustained any measurable amount of leaf injury. There was no appreciable difference in yield between the fumigated and control plots, the mean yield of the fumigated plots being $102.6\% \pm 1.19$, for the green weight, and $100.2\% \pm 1.29$, for the dry weight. It is clear from these experiments that whatever temporary reduction in the carbon dioxide assimilation may have resulted from these short treatments at the higher concentrations, as will be shown in Chapter XV, this effect was transitory in nature and after removal of the gas recovery of normal assimilation was sufficiently rapid to prevent a reduction in yield.

INFLUENCE OF INCREASING LEAF INJURY ON YIELD

With increasing leaf injury the alfalfa plant shows a reduction in yield. It is probable that alfalfa is more sensitive to slight markings by sulphur dioxide than barley, and its capacity for recovery from the effects of injurious fumigations is less pronounced. In Table XIII are shown the yield data on a series of plots in which the leaf tissue was injured to the extent of 3 to 9%, with the average 6.3%. A considerably greater proportion of leaves was found to be marked by sulphur dioxide, but most of these markings were relatively slight and from their distribution could not seriously affect the growth of the uninjured portions of the leaves. It was thought advisable to classify these leaves in the two categories of "marked" and "injured" leaves, the latter representing the proportion of leaves destroyed, in order to see which class showed the better correlation with the yield data. The average percentage of marked leaves shown in Table XIII is 20.2 and the injured leaves, 6.3, while the mean yield calculated in percentage of control is 89.6 for the green weight, and 92.1 for the dry weight, with standard errors of 1.90 and 1.97% respectively.

Another series of fumigation experiments, in which the leaf destruction varied from 10 to 28%, is shown in Table XIV. The average percentage of completely injured leaves in this case is 18.0, and the average percentage of marked leaves, 42.3. The mean green weight of the fumigated plots is 87.8%, and the dry weight, 89% of the control.

TABLE XIII
EFFECT OF SULPHUR DIOXIDE ON YIELD OF ALFALFA, SHOWING INFLUENCE OF INCREASING LEAF INJURY

Fumigated plot	Sulphur dioxide treatment		No. of plants	Percentage of		Yield			
	Average conc., p.p.m.	Duration, hr.		marked leaves	injured leaves	Fumigated plots		Control plots	
						Green wt., gm.	Dry wt., gm.	Green wt., gm.	Dry wt., gm.
Series I—Three to nine per cent leaf injury									
E-18	0.35	91.0	52	chlorotic	5	4,450	836	4,670	880
B-13	0.38	72.0	52	18	6	4,290	786	4,740	877
B-8	0.48	97.5	90	8	—	5,002	1,080	5,675	1,140
E-14	0.54	44.0	52	25	3	3,840	691	4,037	755
C-9	0.78	22.5	52	18	6	3,505	705	4,760	914
G-11	0.84	29.0	52	11	5	4,350	813	4,660	889
D-10	0.88	12.0	52	15	4	3,974	743	4,499	821
C-5	0.96	8.5	52	28	9	2,375	545	2,770	616
B-12	0.96	17.0	52	31	7	5,280	1,056	5,475	1,095
H-17	1.04	7.0	52	11	3	5,630	1,077	5,890	995
C-7	1.21	7.0	52	26	8	3,165	636	4,460	889
H-15	1.32	4.0	52	11	6	5,250	1,055	5,430	1,091
D-9	1.33	4.0	52	25	—	3,290	717	3,560	790
C-15	1.37	6.0	52	35	9	4,070	777	4,153	748
D-8	1.40	7.0	52	26	7	3,730	780	4,330	839
G-14	1.91	6.0	52	17	9	4,930	962	4,970	978
F-15	2.41	4.0	52	24	9	4,670	869	5,480	943
E-16	2.46	14.5	52	15	5	5,080	945	6,220	1,077
Average				20.2	6.3				
Mean yield calculated as percentage of adjacent control									
Standard deviation, %									
Standard deviation of mean, %									
						89.6	92.1		
						8.03	8.35		
						1.90	1.97		

TABLE XIV
EFFECT OF SULPHUR DIOXIDE ON YIELD OF ALFALFA, SHOWING INFLUENCE OF INCREASING LEAF INJURY

Fumigated plot	Sulphur dioxide treatment		No. of plants	Percentage of		Yield			
	Average conc., p.p.m.	Duration, hr.		marked leaves	injured leaves	Fumigated plots		Control plots	
						Green wt., gm.	Dry wt., gm.	Green wt., gm.	Dry wt., gm.
Series II—Ten to twenty-eight per cent leaf injury									
B-8	0.46	48.0	52	52	15	2,040	408	2,565	513
B-2	0.47	65.0	90	10	—	4,970	965	5,875	1,170
C-14	0.82	8.0	52	56	28	4,800	965	5,035	1,036
A-12	0.88	8.0	52	40	11	3,710	850	4,300	921
H-5	0.89	29.0	52	35	15	3,920	800	4,420	888
G-20	0.94	26.75	52	21	16	4,100	857	4,870	972
E-12	0.95	53.0	52	43	18	3,840	726	4,125	730
G-6	1.00	7.0	52	56	20	3,580	723	3,920	803
B-10	1.04	50.5	90	—	24	4,970	1,015	6,817	1,387
F-11	1.04	24.0	52	54	17	3,950	703	4,105	687
D-8	1.05	24.0	52	56	21	3,470	700	3,839	742
G-18	1.12	21.0	52	35	20	3,950	801	4,980	966
D-14	1.13	3.5	52	54	25	4,220	738	4,427	763
B-15	1.25	5.5	52	37	14	3,770	769	4,430	877
D-6	1.40	18.25	52	42	15	2,375	512	3,163	671
C-3	1.46	15.0	52	—	12	3,751	641	3,420	635
B-11	1.46	6.5	52	43	19	3,260	816	4,060	918
C-12	1.48	6.5	52	43	10	4,190	965	5,270	1,133
A-11	1.51	27.5	90	—	17	5,760	1,095	6,485	1,328
G-16	2.05	6.0	52	35	25	4,600	874	4,990	982
E-12	2.38	14.0	52	41	11	4,400	831	5,370	924
D-7	2.96	4.0	52	50	25	3,680	787	3,610	832
Average				42.3	18.0				
Mean yield calculated as percentage of adjacent control									
Standard deviation, %									
Standard deviation of mean, %									
				87.8	89.0				
				8.85	7.51				
				1.88	1.60				

TABLE XV
EFFECT OF SULPHUR DIOXIDE ON YIELD OF ALFALFA, SHOWING INFLUENCE OF INCREASING LEAF INJURY

Fumigated plot	Sulphur dioxide treatment		No. of plants	Percentage of		Yield			
	Average conc., p.p.m.	Duration, hr.		marked leaves	injured leaves	Fumigated plots		Control plots	
						Green wt., gm.	Dry wt., gm.	Green wt., gm.	Dry wt., gm.
Series III—Twenty-nine to fifty-five per cent leaf injury									
A-13	0.55	45.5	90	60	32	4,970	994	6,060	1,144
A-9	0.90	24.0	52	79	29	1,870	375	2,270	454
A-7	1.10	60.0	90	76	37	4,970	995	6,287	1,263
F-15	1.25	32.5	52	76	48	3,275	619	3,890	720
C-13	1.66 } 0.30 {	4.0 } 2.5 }	52	80	41	4,125	744	4,653	803
F-13	1.77	38.5	52	66	49	2,940	524	4,030	728
D-4	1.91	5.0	52	53	29	2,150	457	2,825	576
F-7	2.00	13.0	52	81	55	3,615	687	4,070	774
B-12	2.00	14.0	90	61	32	5,535	1,028	6,627	1,243
F-11	2.47	7.5	52	65	30	3,650	705	4,050	762
E-14	2.49	4.17	52	45	—	5,240	916	5,795	1,050
Average				67.5	38.0				
Mean yield calculated as percentage of adjacent control									
Standard deviation, %									
Standard deviation of mean, %									
						83.5	84.4		
						5.77	6.24		
						1.74	1.88		

In the case of plots fumigated with sulphur dioxide under such conditions that the average leaf injury was 38.0% and the average percentage of marked leaves 67.5, the mean yield is reduced to 83.5% for the green weight and to 84.4% for the dry weight, as shown in Table XV.

The data in Tables XIII to XV show the extent of the reduction in yield that follows the application of injurious sulphur dioxide treatments during the growth of a single crop of alfalfa. The fumigations were carried out during the period from about ten days to three weeks after the cutting of the previous crop. Since sulphur dioxide effects in alfalfa are confined mainly to lesions on the actively growing, middle-aged leaves, the youngest and oldest leaves being very seldom marked and no markings ever having been observed on the stems and buds in the severest treatments applied at Summerland, the most injurious fumigations cannot be expected to greatly reduce the yield of a single crop. In a few instances at Summerland, plots were treated with such high concentrations of gas that the plants were almost completely defoliated. However, no injury appeared on the buds and stems, and within a few days a considerable amount of new leaf tissue made its appearance.

A number of experiments were carried out during the flowering period of the alfalfa, and it is considered advisable to treat the yield of these plots separately. The results shown in Table XVI indicate that with the average leaf destruction as high as 8.8%, and the average percentage of marked leaves, 33.9%, there is no appreciable reduction in yield when the alfalfa is fumigated during the flowering period. The small differences between the fumigated and control plots for both green and dry weights are less than twice the standard error and, therefore, of no significance. These results may be accounted for by the fact that only a relatively small percentage of the leaves marked by sulphur dioxide were shed in these experiments. Most of the injured leaves were present on the plants at the time of harvest.

INFLUENCE OF SULPHUR DIOXIDE UPON YIELD OF SUBSEQUENT CROP

The effect of fumigating one, two and three successive crops of alfalfa on the yield of the subsequent unfumigated crop is shown in Table XVII. In the case of a series of fumigations which reduced the mean yield of the first crop to 91.6%, the subsequent unfumigated second crop was found to weigh 98.1% of the control. This difference is not significant. In a further series of fumigations carried out on the first and second crops, in which the mean yield was 98.2% and 94.7% respectively, the yield of the subsequent unfumigated crop was 101.3%. Again, with fumigations carried out on three successive crops, the mean yield of the first crop being 81.5%, the second crop 92.3% and the third crop not harvested, the subsequent unfumigated crop the following year weighed 93.3% of the control, with a standard error of 4.5%. Even in the last case the unfumigated crop has not been affected to an appreciable extent by the gas treatment of the previous crops. It is evident, therefore, that the

TABLE XVI
EFFECT OF SULPHUR DIOXIDE FUMIGATION DURING THE FLOWERING PERIOD ON YIELD OF ALFALFA

Fumigated plot	Sulphur dioxide treatment		No. of plants	Percentage of		Yield			
	Average conc., p.p.m.	Duration, hr.		marked leaves	injured leaves	Fumigated plots		Control plots	
						Green wt., gm.	Dry wt., gm.	Green wt., gm.	Dry wt., gm.
E-10	0.60	68.0	52	39	10	3.950	640	4.145	690
E-6	0.64	11.25	52	48	15	3.615	767	3.950	709
C-5	0.96	8.5	52	28	9	2.375	545	2.770	616
E-8	0.99	13.0	52	50	17	4.070	737	3.917	685
D-2	1.25	3.0	52	27	8	3.130	596	3.268	603
E-2	1.25	3.0	52	23	3	3.167	548	3.026	618
F-3	1.25	8.0	52	9	2	2.649	531	2.759	594
E-4	1.25	8.0	52	12	1	2.624	494	2.630	578
F-1	1.26	20.0	52	59	24	3.271	589	3.225	588
F-9	1.50	19.0	52	44	7	4.070	798	4.105	720
C-3	2.00	16.0	52	—	1	4.290	816	4.290	834
Average				33.9	8.8				
Mean yield calculated as percentage of adjacent control									
Standard deviation, %									
Standard deviation of mean, %									

TABLE XVII
INFLUENCE OF SULPHUR DIOXIDE FUMIGATIONS UPON YIELD OF THE
SUBSEQUENT CROP OF ALFALFA

Crop 1935	Sulphur dioxide treatment		Percentage of		Harvest weight in per- centage of control	
	Average conc., p.p.m.	Duration, hr.	marked leaves	injured leaves	Current crop	Subsequent unfumigated crop, 1935
<i>I—Fumigation of a single crop</i>						
First	1.77	38.5	66	49	72.9	95.3
First	1.04	24.0	54	17	96.2	100.5
First	0.64	11.5	48	15	91.5	100.0
First	0.99	13.0	50	17	104.0	107.0
First	0.60	68.0	39	10	95.4	94.4
First	0.95	53.0	43	18	93.1	100.5
First	0.54	44.0	25	3	95.2	93.8
First	1.25	32.5	76	48	84.2	93.1
Mean yield					91.6	98.1
Standard error of the mean					3.36	1.69
<i>II—Fumigation of two crops</i>						
						First crop 1936
First	0.20	87.5	none	none	105.8	
Second	0.10	504.0	none	none	93.6	106.3
First	2.00	14.0	61	32	83.4	
Second	0.96	17.0	31	7	96.4	98.9
First	2.00	16.0	—	1	100.0	
Second	1.46	15.0	44	12	109.5	107.8
First	0.96	8.5	28	9	85.7	
Second	1.56	8.0	24	4	106.1	100.0
First	0.80	7.5	none	none	101.1	
Second	0.37	378.0	52	8	78.5	100.5
First	1.40	7.0	26	7	86.2	
Second	1.05	24.0	56	21	90.4	103.8
First	0.86	7.5	slight	slight	104.2	
Second	0.88	12.0	15	4	88.3	95.3
First	0.50	37.5	29.6	—	105.5	
Third	2.47	2.0	slight	slight	—	102.7
First	0.28	87.5	chlorotic	—	112.3	
Third	1.46	2.25	15	6	—	96.2
			First crop	Second crop	Subsequent unfumigated crop	
Mean yield			98.2	94.7	101.3	
Standard error of the mean			3.5	4.01	1.42	

TABLE XVII—Continued
INFLUENCE OF SULPHUR DIOXIDE FUMIGATIONS UPON YIELD OF THE
SUBSEQUENT CROP OF ALFALFA

Crop 1935	Sulphur dioxide treatment		Percentage of		Harvest weight in per- centage of control	
	Average conc., p.p.m.	Duration, hr.	marked leaves	injured leaves	Current crop	Subsequent unfumigated crop. 1936
III—Fumigation of three crops						
First	0.48	97.5	8	—	88.0	103.0
Second	0.46	48.0	52	15	79.5	
Third	1.06	5.5	slight	—	—	
First	1.80	8.5	—*	13	77.8	79.9
Second	0.90	24.0	79	29	82.4	
Third	1.80	1.0	24	4	—	
First	1.10	60.0	76	37	79.1	99.0
Second	1.06	11.0	23	8	88.0	
Third	2.93	2.5	15	2	—	
First	1.51	27.5	—*	17	88.9	106.8
Second	0.87	17.0	9	slight	99.0	
Third	1.42	3.0	—*	—	—	
First	1.04	50.5	—*	24	72.9	84.2
Second	0.50	10.0	32	slight	112.5	
Third	2.30	7.0	47	18	—	
First	1.21	7.0	26	8	82.1	86.6
Second	1.48	12.5	53	21	—	
Third	0.56	22.0	slight	—	—	
		First crop	Second crop	Third crop	Subsequent unfumigated crop	
Mean yield		81.5	92.3	—	93.3	
Standard error of the mean		2.52	6.03	—	4.5	

* Percentage of marked leaves not estimated

residual effect of sulphur dioxide fumigation is negligible in the case of single, double, or even triple crop treatments where the reduction in yield of the fumigated crops is of the order discussed here.

EFFECT OF SULPHUR DIOXIDE ON HEIGHT GROWTH

The effect of sulphur dioxide on height growth was studied by measurements on 20 plants selected at random in each of a number of plots immediately prior to sulphur dioxide treatment and at the time of cutting. The plants were designated by tags and the increase in height was determined over the period of the investigation. The average measurements for a series of plots fumigated during the pre-flowering period, and also during the flowering stage, are shown in Table XVIII. In the case of experiments carried out during the flowering period, the plants were allowed to mature for 26 days before the final height measurements were taken.

Plants exposed during the pre-flowering period to concentrations of sulphur dioxide ranging from 0.15 to 1.01 p.p.m. show no diminution in normal height growth even though some of the treatments caused slight marking on a small number of leaves. A reduction in height development is evident only in those experiments where the proportion of marked leaves is appreciable. In the series of experiments on alfalfa in flower, the average height increase of the fumigated plants is 2.6 cm. greater than that of the controls, although the average percentage of marked leaves is 3.3.

As in the case of the yield tests, the results of these experiments indicate that there is no residual effect on growth after treatment with sulphur dioxide if the fumigation does not injure the leaf tissue to an appreciable extent.

It is interesting to observe that alfalfa when allowed to mature for a period of nearly one month beyond the flower stage develops a considerable amount of chlorosis. Only a limited number of new leaders bearing green leaves appear during this period, while leaves on the old leaders assume yellow, bronze and reddish discolorations, characteristic of senescence. This is equally true of the untreated and fumigated plants.

Discussion

The yield studies on alfalfa are summarized in Tables XIX and XX, with the data arranged in order of increasing severity of sulphur dioxide treatment as well as increasing leaf destruction. The yield of alfalfa is not affected by exposure to sulphur dioxide under relatively wide limits of concentration and duration if there is no resultant visible injury to the leaves. This applies with equal emphasis to barley.

It has been considered advisable to treat the fumigation data in relation to concentration and duration only. The plants were grown under normal conditions as regards temperature, humidity, and soil moisture. It is obvious, therefore, that if sulphur dioxide exerts an invisible effect on growth as implied by the invisible injury theory, this would have been demonstrated in this work. On the contrary, prolonged treatment with low concentrations of sulphur dioxide in the absence of visible markings not only did not reduce the yield but in some cases brought about slight increases.

With regard to the limiting concentrations affecting growth and yield of plants, these will be to a large extent dependent upon the influence of external factors which increase or decrease the susceptibility of the plant and, in turn, govern the rate of absorption of gas and, consequently, the extent of the markings produced by a given treatment. Environmental factors such as temperature, humidity, light, soil moisture and age of the plant, all have a considerable influence on susceptibility to sulphur dioxide, as already indicated in Chapter XI. However, the data in the yield studies indicate that with concen-

TABLE XVIII
EFFECT OF SULPHUR DIOXIDE TREATMENT ON HEIGHT GROWTH OF ALFALFA

Plot	Sulphur dioxide treatment		Percentage leaves marked		Height of fumigated plants, cm.			Height of control plants, cm.		
	Conc., p.p.m.	Duration, hr.			when treated	when cut	Increase	when treated	when cut	Increase
<i>Growing alfalfa—no appreciable leaf injury</i>										
C-10	0.15	167.0	trace		49	73	24	47	71	24
D-7	0.36	8.0	0		47	57	10	43	53	10
D-13	0.37	9.5	4		44	61	17	40	56	16
	0.67	7.0								
C-16	0.55	4.0	trace		35	66	31	33	64	31
D-11	0.56	16.0	trace		43	60	17	39	56	17
C-14	0.61	4.0	0		37	68	31	33	64	31
D-9	0.99	8.0	2		44	53	9	43	53	10
D-15	1.01	4.0	1		41	65	24	36	60	24
F-13	1.38	7.25	2		26	67	41	22	66	44
<i>Growing alfalfa—appreciable leaf injury</i>										
E-18	0.35	91.0	*5.0		19	66	47	21	72	51
C-18	0.60	16.5	21.2		33	62	29	29	65	36
F-15	2.43	4.0	24.0		24	62	38	25	67	42
<i>Alfalfa in flower—slight injury</i>										
H-4	0.34	12.0	1.0		86	98	12	85	95	10
G-8	0.34	70.5	2.3		92	110	18	98	109	11
G-3	0.57	4.0	0		82	96	14	82	101	19
G-6	0.35	0.67								
	0.64	3.5	1.3		90	106	16	89	105	16
H-9	0.62	67.0	10.5		88	102	14	96	109	13
H-7	1.06	5.0	4.6		89	107	18	84	91	7

* An undetermined number of leaves showed additional chlorotic symptoms.

TABLE XIX
EFFECT OF SULPHUR DIOXIDE ON YIELD OF ALFALFA

No. of fumigated plots	No. of control plots	Sulphur dioxide treatment				Injured leaves, average %	Mean yield of crop, percentage of adjacent controls							
		Concentration of SO ₂ , p.p.m.			Duration, hr.		Green weight			Dry weight				
		Min.	Max.	Av.	Min.		Max.	Av.	Mean %	Standard deviation %	Standard deviation of mean %	Mean %	Standard deviation %	Standard deviation of mean %
No visible markings														
12	12	0.10	0.30	0.167	66.5	602.0	256.2	0	100.4	7.96	2.29	103.0	7.51	2.16
11	11	0.36	0.66	0.554	4.0	16.5	8.29	0	104.8	8.10	2.44	99.6	6.92	2.08
12	12	0.76	1.15	1.008	4.0	17.0	7.60	0	101.1	2.94	0.85	100.8	7.52	2.17
29	29	0.26	2.51	0.885	4.0	17.0	7.48	0	102.6	6.43	1.19	100.2	6.96	1.29
Alfalfa visibly injured by treatment														
13	13	0.82	1.37	1.08	3.5	17.0	7.45	14.7	92.2	4.43	1.23	94.4	6.03	1.67
5	5	1.91	2.49	2.27	4.0	7.5	5.54	18.2	91.4	5.0	2.23	91.8	4.28	1.91
3	3	1.40	1.48	1.45	6.5	7.0	6.67	12.0	82.0	3.70	2.13	89.0	3.96	2.28
7	7	0.35	0.55	0.461	44.0	97.5	66.14	11.3	87.9	6.18	2.34	88.6	5.85	2.21
12	12	0.78	1.25	0.992	21.0	60.0	33.0	21.3	84.7	7.70	2.22	87.0	8.65	2.50
4	4	2.00	2.46	2.21	13.0	14.5	13.87	25.7	83.9	3.30	1.65	87.2	3.24	1.62
3	3	1.40	1.77	1.56	18.2	38.5	28.08	27.0	78.9	8.66	5.00	76.8	5.35	3.08

trations of the magnitude of 0.10 to 0.30 p.p.m. of sulphur dioxide in air, there is little likelihood of an effect on the yield under normal conditions of humidity, soil moisture, temperature and light, even when after prolonged exposure slight markings are occasionally produced. Even with higher concentrations of gas, above 0.50 p.p.m., there is no reduction in yield if the exposures are not prolonged sufficiently to visibly injure the leaf tissue.

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CHAPTER XIV

**EFFECT OF FUMIGATION ON SOME CHEMICAL CONSTITUENTS
OF BARLEY, WHEAT AND ALFALFA**

BY MORRIS KATZ AND D. S. PASTERNAK

Introduction

It has been shown that plants grown in the Trail-Northport area contain much higher amounts of sulphur than those grown outside the smoke zone. The question thus arises as to whether absorption of abnormal amounts of sulphur affects the feeding value of crop plants, by changing the carbohydrate-protein ratio, or in some other manner. The literature contains some information on the composition of plants showing visible signs of sulphur damage, but little attention has been paid to plants subject only to infrequent exposure to sulphur dioxide, or exposure to such low concentrations that visible damage did not occur.

The work described in this chapter was undertaken to provide more definite information on the relation between the concentration of sulphur dioxide in the atmosphere, absorption of sulphur by leaves, and the resulting effect on the composition of the leaves and grain. The first part of the investigation deals with the relation between sulphur and protein content of alfalfa collected at various distances from the Trail smelter. The second part describes the results of controlled experiments conducted on plots of alfalfa, barley and winter wheat grown in cabinets.

Literature Review

Leaves of plants which show the symptoms associated with chronic sulphur dioxide injury have, according to Stoklasa (5, p. 130), a lower starch content than normal leaves. Bredemann (2, p. 291) is of the opinion that a lowering of the starch content can be established only in the case of chronic injury, as in cases of acute injury the leaf cells die suddenly and the starch is fixed at the level which existed prior to the destruction of the cells. He found a considerable variation in the starch content of imbedded specimens which had been injured by smoke.

There is very little information available in the literature on the effect of sulphur dioxide under known conditions of gas exposure on the composition of the plant. Wells (8) refers to the work of O'Gara who found that plants both marked and unmarked by sulphur dioxide in experimental fumigations (conditions not stated) showed an increase in protein content. Swain (6) reports that "invisible injury" tests with repeated mild fumigations at low

concentrations insufficient to cause foliar markings, carried out daily during the entire period of growth of crops, resulted in a higher sulphur and protein content, and no reduction in carbohydrate and fat content, and in yield, in comparison with untreated crops.

Kock *et al.*, in fumigation tests on red clover (3), found no effect on the total digestible or indigestible protein with concentrations of 5 to 10 p.p.m. or even higher in exposures of one to four hours. There was no deleterious effect observable on the fodder value of the clover. Later experiments, however, under more severe conditions brought about a decrease in the total protein and an increase in the indigestible protein of the clover (4).

Direct feeding experiments, with animals, of alfalfa hay from a smoke area in comparison with similar hay outside the range of smelter influence are reported by Widtsoe (9) and more recently by Cunningham and Addington (1). Widtsoe found that in tests of 16 weeks' duration there was no effect on the relative milk production, weight of butter fat, and weight of animals when cows were fed alfalfa hay exposed to sulphur dioxide from smelters in the vicinity of Murray, Utah. The recent work of Cunningham and Addington is of great interest in that the gas conditions to which the alfalfa was exposed in their tests are known with fair accuracy. The alfalfa was located in a field about three miles from a smelter and had been marked by sulphur dioxide on four occasions during the growth of the crop. According to the records of an automatic sulphur dioxide recorder stationed in this field, the alfalfa was exposed to gas visitations of low concentrations almost daily, the readings varying from traces to 0.5 p.p.m. during the time when no visible symptoms were observed, but rising to maxima of 1.2, 3.4, and 0.82 p.p.m. on the occasions when the leaflets were injured. The average number of leaflets injured in the alfalfa selected for the feeding trials was over 20%. A statistical analysis of the individual records of the cows indicated that there was no significant effect on the feeding value of the exposed hay in comparison with similar hay collected at a point beyond the zone of smoke influence.

Experimental

Analytical Methods

The methods of analysis outlined as follows were, with only slight modifications, those given by the Association of Official Agricultural Chemists (official and tentative methods of analysis). The results in the tables are reported on a dry weight basis.

METHODS FOR GREEN PLANTS

A sufficient number of plants was selected from each plot so as to make the sample representative of the average composition of the entire plot.

Fumigated and control plots were sampled at the same time. The plants were collected in glass containers packed in an ice-salt freezing mixture and the leaves rapidly and carefully separated from stems and petioles.

Preservation of Samples

(a) *For total sulphur and nitrogen.* The samples were thoroughly freed of any adhering soil, rapidly dried in air at 70°C., ground, and preserved in tightly stoppered bottles.

(b) *For carbohydrates.* The fresh material was washed free of soil and rapidly chopped into fine pieces. Twenty grams of the sample was treated with about 1.0 gm. of calcium carbonate and 90 cc. of 95% redistilled alcohol. The mixture was refluxed on the water bath for 45 min. The samples were then stored in the alcohol in a refrigerator until required for analysis.

Total Sulphur

This was determined by the sodium peroxide fusion method using with 1.5 gm. of plant material, about 7 gm. of anhydrous sodium carbonate and about 10 gm. of sodium peroxide.

Soluble Sulphates

A solution of 5 cc. of concentrated hydrochloric acid in 400 cc. of distilled water was added to 50 gm. of freshly collected leaves and heated near the boiling point for about two hours. The mixture was filtered, using suction, and the filtrate evaporated to dryness. The residue, after cooling, was treated with 200 cc. of distilled water containing 1 cc. of concentrated hydrochloric acid, and the mixture boiled for some time without stirring. After decanting the supernatant liquid through a filter, the residue was boiled for a few minutes with a further 75 cc. of distilled water. The residue was then transferred to the filter paper and washed. The combined filtrate was acidified with 1.5 cc. of concentrated hydrochloric acid, heated to the boiling point, and the sulphate was precipitated by addition of 10% barium chloride. The barium sulphate was then determined gravimetrically.

Sulphurous Acid

Fifty grams of freshly collected material was treated with 20 cc. of 20% phosphoric acid, 200 cc. of distilled water and 1 gm. of sodium bicarbonate, dissolved in 15 cc. of distilled water. The mixture was distilled until 150 cc. of distillate was collected in about 100 cc. of nearly saturated bromine water. The bromine solution was then boiled to expel excess of bromine, diluted to about 250 cc., acidified with 1.5 cc. concentrated hydrochloric acid, heated to boiling, and the sulphuric acid precipitated with 10% barium chloride solution, the barium sulphate being determined gravimetrically.

Nitrogen

This was determined by the Kjeldahl-Gunning-Arnold method for organic and ammoniacal nitrogen on about 1 gm. of dried material.

Soluble Nitrogen

About 3 gm. of the dried sample was extracted in a Soxhlet with 95% alcohol overnight. The alcoholic extract was placed in a Kjeldahl flask and the alcohol removed on the water-bath. The residue was dried in an oven at 75°C. and the nitrogen then determined as above.

Reducing Sugars and Sucrose

The samples, prepared as already described for the estimation of carbohydrates, were extracted repeatedly with hot 80% alcohol, and finally the residue was dried, very finely ground and extracted for 12 hr. in a Soxhlet apparatus with 80% alcohol. The alcoholic extracts were filtered, combined and made up to a definite volume. The residue was dried and kept for the determination of polysaccharides. The alcoholic extract was clarified in the usual manner by the addition of sufficient saturated neutral lead acetate.

The reducing sugars and sucrose were determined on aliquots of the alcoholic extract, the reducing sugars by the general method of Munson and Walker (reduction with Fehling's solution) and the sucrose by the same method after acid inversion.

Acid-hydrolyzable Polysaccharides

This was determined on the residue remaining from the 80% alcohol extraction. A weighed quantity of the sample, after thorough washing with cold distilled water, was heated with 200 cc. of water and 20 cc. of hydrochloric acid (sp. gr. 1.125) under reflux for about five hours. The mixture was nearly neutralized with sodium hydroxide, made up to a definite volume and the dextrose determined in an aliquot by the method of Munson and Walker.

METHODS FOR GRAIN

Preparation of Sample for Sugar Determination

About 125 cc. of 50% alcohol by volume was added to a 10 gm. sample of ground and dried grain, and also about 1 gm. of calcium carbonate. The mixture was boiled for one hour under reflux and after standing overnight was made up to 250 cc. volume by addition of 95% alcohol. Exactly 200 cc. of supernatant liquid was removed and evaporated to 20 to 30 cc. volume on the water bath. The solution was clarified by the addition of sufficient

neutral lead acetate solution. After standing about 30 min. the mixture was diluted to a volume of 100 cc. with water, mixed and filtered. Anhydrous sodium carbonate was added to the filtrate in sufficient amount to precipitate the lead and the solution again filtered.

Reducing Sugars

An aliquot of the above filtrate was treated with Fehling's solution and the precipitated cuprous oxide determined by the volumetric thiosulphate method.

Sucrose

An aliquot of the above filtrate was neutralized with hydrochloric acid, 5 cc. of strong hydrochloric added, and the inversion completed by allowing to stand overnight at 25°C. The solution was then neutralized with sodium carbonate, and the reducing sugars determined as above with Fehling's solution.

Acid-hydrolyzable Polysaccharides

This was determined on 2.5 gm. samples of the ground and dried grain. After thorough washing with cold water, the insoluble residue was heated for about three hours with a mixture of 20 cc. hydrochloric acid (sp. gr. 1.125) and 200 cc. water under a reflux condenser. The mixture was then cooled, nearly neutralized with sodium hydroxide, made up to a volume of 250 cc. and after filtering, the dextrose was determined in an aliquot of the filtrate by Munson and Walker's method.

The Nitrogen and Total Sulphur Content of Alfalfa in Relation to Distance from Trail, B.C.

In June, 1934, a study was made of the nitrogen and total sulphur content of alfalfa leaves from a representative number of plants collected at 35 different points south of Trail, B.C., within the smoke zone, and at 17 points outside the smoke zone, during the flowering period of the first crop immediately prior to harvesting. During the growth of this crop the plants within the smoke zone were subjected to frequent visitations of sulphur dioxide of variable duration and concentration. The average and maximum concentrations at points 15 and 30 miles south of Trail are given in Table I.

At the recorder station 15 miles south of Trail the first crop of alfalfa was subjected to about double the duration and about three times the average concentration of gas when compared with the point 30 miles south.

TABLE I

Distance, miles	Total time of exposure to sulphur dioxide, hr.	Maximum concentration, p.p.m.	Average of concentrations above trace values, p.p.m.	Average of all readings, p.p.m.
15	405	1.00	0.105	0.0227
30	235	0.28	0.055	0.0077

The concentrations at points closer to Trail, *i.e.*, five to six miles south of Trail, are considerably higher on the average than those occurring 15 miles south (cf. Chapter II). On the other hand, at distances greater than 30 miles the sulphur dioxide concentrations decrease very gradually.

The total sulphur and nitrogen contents of the alfalfa leaves at the various stations are shown in Tables II, III and IV. The values of their correlation coefficients with distance from the source of sulphur dioxide at Trail and the correlations between total sulphur and nitrogen content are shown in Table V. Within the main Columbia River valley there is a significant inverse correlation between the total sulphur in alfalfa leaves and distance from Trail. Within the tributary valleys the decrease in sulphur content

TABLE II

NITROGEN AND TOTAL SULPHUR CONTENT OF LEAVES OF FIRST CROP ALFALFA
Collections made along Columbia River valley in Trail smoke zone in June 1934

Location	Distance south of Trail, B.C., miles	Organic and ammoniacal nitrogen, %	Total sulphur, %
In British Columbia	6.0	4.77	1.27
	6.0	4.38	1.18
	6.5	3.83	1.10
	7.0	4.04	1.20
In Stevens County, Washington	12.0	4.48	0.904
	15.0	4.46	0.676
	15.0	4.52	1.00
	17.0	4.29	0.688
	17.0	3.85	0.540
	18.5	4.24	0.656
	25.0	4.06	0.592
	27.0	3.57	0.672
	29.0	4.10	0.602
	30.0	4.10	0.784
	31.0	4.23	0.524
	36.0	4.26	0.756
	39.0	3.97	0.835
	47.0	4.35	0.730
	52.0	4.16	0.555
	53.5	3.91	0.615

TABLE III

NITROGEN AND TOTAL SULPHUR CONTENT OF LEAVES OF FIRST CROP ALFALFA
Collections made along tributary valleys of the Columbia River in smoke zone in June, 1934

Location	Distance from Columbia River, miles	Distance of mouth of creek from Trail, miles	Nitrogen, %	Total sulphur, %
Cedar Creek valley	1.5	10	3.90	0.580
	3.5		4.49	0.490
	4.0		4.41	0.342
	5.0		4.16	0.388
	10.0		4.07	0.328
Sheep Creek valley	2.0	19	3.92	0.826
	3.0		4.10	0.562
	5.0		4.55	0.525
	6.0		5.15	0.596
Deep Creek valley	1.0	18.5	3.80	0.574
	3.0		4.42	0.625
	4.5		4.04	0.685
	5.5		3.87	0.596
	7.0		3.97	0.526
	8.0		3.82	0.258

TABLE IV

NITROGEN AND TOTAL SULPHUR CONTENT OF LEAVES OF FIRST CROP ALFALFA
Collections made in valleys outside the smoke zone in June 1934

Location	Distance in miles	Distance of mouth of river from Trail, miles	Nitrogen, %	Total sulphur, %
Kettle River valley*	2.0	48	4.42	0.666
	4.5		4.13	0.660
	14.0		3.98	0.266
	17.8		3.75	0.326
Colville Valley, Washington				
South of Aladdin	2.0	—	3.97	0.216
North of Colville	4.0		4.01	0.460
South of Colville	3.0		4.38	0.566
South of Colville	5.4		4.23	0.386
South of Colville	9.0		4.72	0.502
South of Colville	16.8		4.13	0.416
South of Colville	20.0		4.18	0.474
South of Colville	24.3		4.25	0.472
Grand Forks valley**	0.8	—	4.16	0.456
	1.5		4.16	0.300
	1.8		3.87	0.444
	2.5		3.44	0.380

* Distances from Columbia River

** Distances from Grand Forks, B.C.

TABLE V

COEFFICIENTS OF CORRELATION BETWEEN DISTANCE FROM TRAIL AND SULPHUR OR NITROGEN, AND BETWEEN SULPHUR AND NITROGEN, OF ALFALFA LEAVES

Stations located in	Coefficients of correlation between		
	Distance and sulphur	Distance and nitrogen	Sulphur and nitrogen
Main Columbia River valley	-0.60**	-0.27	+0.30
Tributary valleys	-0.46*	+0.06	—
Areas outside smoke zone	—	—	+0.44

* Denotes that the 5% and ** that the 1% level of significance is exceeded.

is scarcely significant, owing to the fact that the plants are not in the main path of the smoke and sulphur dioxide visitations occur with considerably less frequency and in lower concentrations (cf. Chapters II and IV). With regard to the nitrogen content of the alfalfa, however, no significant correlation was found with distance in the smoke zone. The sulphur dioxide visitations had no effect therefore on the protein content of the alfalfa. Outside the smoke area some correlation was found between high sulphur and high protein content of the alfalfa. Within the main Columbia River valley, however, this effect is masked by the presence of sulphur dioxide in the atmosphere and its absorption by the leaves (cf. Table V).

At regular intervals during April and May, 1934, samples of alfalfa leaves were collected from plants growing near the sulphur dioxide recorder stations at 15 and 30 miles south of Trail. The analytical data given in Table VI illustrate the rate of increase in sulphur through atmospheric absorption at the two different points, and the effect of this absorption on nitrogen content. The variation in sulphur content of the soil at the two points was negligible. At the Stroh experimental plot the alfalfa leaves increase in sulphur content significantly with age during the growth of the crop. At the Marble station, 15 miles farther south, the atmospheric sulphur dioxide concentrations are so low that the increase in sulphur with age is slight, the absorption of sulphur being to a certain extent masked by the appearance of fresh, newly expanded leaves on the plants in the intervals between the sampling periods. The nitrogen content of the leaves decreases with age in a normal manner similar to that shown by collections made in a sulphur-dioxide-free atmosphere at the Dominion Experimental Station, Summerland, B.C. The data are shown in Tables VII and VIII. Table VII indicates the variation in

moisture, sulphur and nitrogen of alfalfa leaves, stems and roots with age of the plants for collections made in 1935, whereas Table VIII gives the relation between nitrogen and age, of leaves only, in collections made in 1936. In both leaves and stems the moisture and nitrogen decrease with age or advancing maturity of the plant.

TABLE VI

VARIATION IN NITROGEN AND TOTAL SULPHUR CONTENT OF ALFALFA LEAVES DURING GROWTH OF THE FIRST CROP APRIL-JUNE, 1934.

(Results expressed on a dry basis.)

Date of sampling	Nitrogen, %	Total sulphur, %	Remarks
<i>Stroh farm field (non-irrigated)—15 mi. south of Trail, B.C.</i>			
April 13	6.66	0.52	Alfalfa 2 in. high
23	5.74	0.52	6 in. high
May 4	6.07	0.51	Newly-formed terminal leaves
4	6.02	0.70	Lower older leaves
7	6.00	0.68	Green leaves only
7	5.70	0.71	SO ₂ marks on most of leaves
18	5.35	0.70	
24	5.33	0.853	Flowers just beginning to form
<i>Stroh experimental plot (irrigated)—15 mi. south of Trail, B.C.</i>			
April 13	6.87	0.44	2 in. high
24	6.08	0.68	
May 4	6.01	0.67	About 18 in. high
7	6.01	0.76	Green leaves only
7	5.64	0.77	SO ₂ marks on most of leaves
18	5.38	0.86	
24	4.62	0.86	Few days before appearance of flowers
June 7	4.86	1.22	Full flower stage
<i>Near Marble (non-irrigated)—30 mi. south of Trail, B.C.</i>			
April 13	5.99	0.50	2 in. high
24	5.54	0.52	6 in. high
May 5	5.33	0.56	
18	5.14	0.50	20 to 24 in.
26	4.96	0.627	Early bloom stage
<i>Values of correlation coefficient with age of leaves</i>			
	Total sulphur		Nitrogen
Stroh experimental plot	+0.8850		—0.8134
Degree of significance, P	<0.01		Between 0.02 and 0.01

TABLE VII
SULPHUR AND NITROGEN CONTENTS OF ALFALFA AT DIFFERENT STAGES OF MATURITY

Plot no.	Date collected, 1935	Age of plants, days	Moisture, %			Sulphur, %			Nitrogen†, %		
			Leaves	Stems	Roots	Leaves	Stems	Roots	Leaves	Stems	Roots
B-21	June 20	12	81.2	86.0	82.9	0.65	0.27	0.16	6.25	3.89	1.76
	July 20	42	74.8	77.9	73.1	0.64	0.16	0.17	5.13	2.04	1.66
	Sept. 28	42*	75.6	77.3	66.0	0.74	0.24	—	5.03	2.05	1.98
	Oct. 5	42**	—	—	62.4	—	—	0.14	—	—	1.90
E-22	Aug. 6	8	81.8	86.8	77.1	0.66	0.33	—	6.48	4.50	1.77
	Aug. 16	18	79.5	87.9	75.7	0.69	0.35	—	5.40	3.36	1.25
	Sept. 5	38	77.6	79.8	69.5	0.74	0.15	—	5.80	2.00	1.50

* 2nd crop

** 3rd crop

† Correlation coefficient with age: leaves—0.69; stems,—0.81.

TABLE VIII

VARIATION IN NITROGEN CONTENT OF ALFALFA LEAVES WITH AGE
(Plants selected at random from unfumigated plots in 1936)

Age, days	9	13	19	21	23	29	30	31	37	80
Nitrogen†, %	6.39	6.69	5.77	5.32	5.14	5.04	4.94	4.87	4.44	4.03

† Correlation coefficient of nitrogen content with age of leaves, 1935 and 1936 data combined;—0.74.

The moisture content of the roots also decreases with age but there was no correlation, in this case, between age and nitrogen content. There was also no significant degree of correlation found between the sulphur content and age of unfumigated alfalfa, although in some of the analyses in Table VII the leaves tend to increase slightly and the stems to decrease in sulphur content with age. The influence of age of leaves on the content of acid-hydrolyzable polysaccharides is illustrated in Table VIIIA.

TABLE VIIIA

VARIATION IN SUGARS AND POLYSACCHARIDES OF ALFALFA LEAVES WITH AGE

Plot no.	Age, days	Reducing sugars, %	Sucrose, %	Acid-hydrolyzable polysaccharides, %	Total, %
F-22	16	1.01	2.12	18.31	21.44
F-22	37	0.96	1.48	7.67	10.11

Effect of Sulphur Dioxide on Chemical Composition

Experiments under controlled conditions on the effect of sulphur dioxide at various concentrations on the chemical composition of barley and alfalfa were carried out at the Dominion Experimental Station, Summerland, B.C., in the growing seasons of 1931, 1935, and 1936. The investigation was concerned particularly with the effect upon protein, sugar and starch contents of plants fumigated with such concentrations as are known to occur not only in the Trail smoke area but in many other industrial areas. While in the literature some data are available on the effect of high concentrations, in excess of 5 to 10 p.p.m. by volume, there is scarcely any detailed information available on the effect of prolonged treatment with concentrations of 0.10 to 1.0 p.p.m. Yet in most industrial areas or agricultural regions exposed to visitations of sulphur dioxide, the plants are for the most part subjected to

TABLE IX
EFFECT OF PROLONGED SULPHUR DIOXIDE TREATMENT ON BARLEY LEAVES

Sulphur dioxide treatment			Age of plants, days	Leaf no. on plant. No. 1 at bottom	Total sulphur, %		Nitrogen, %	
Concen- tration, p.p.m.	Duration, hr.	Remarks			Fumigated	Control	Fumigated	Control
0.30	35	Continuous treatment, no injury	28	1,2,3 4,5,6 7,8	0.94 0.87 0.57	0.59 0.48 0.41	4.90 5.50 5.58	4.71 5.47 5.45
0.344	48	8 intermittent treatments over a period of 11 days, beginning when plants were 7 days old	18	1,2 3 4 5	0.97 0.59 0.48 0.39	0.30 0.30 0.39 0.27	4.37 4.71 5.24 5.48	4.06 4.84 5.58 5.48
0.280	154	19 intermittent treatments. Sulphur dioxide markings on tips of leaves of about 50% of plants. Many leaves in a chlorotic condition	34	1,2,3, 4,5,6, 7,8	1.37 0.85 0.48	0.52 0.52 0.39	3.09 4.11 4.08	3.79 4.83 4.34
0.270	214	24 intermittent treatments over period of 40 days	55	4,5,6* 7,8*	0.63 0.34	0.52 0.37	3.28 4.02	2.90 4.00

* Samples taken nine days after last sulphur dioxide treatment. Plants had recovered from their chlorotic condition.

fumigations with concentrations considerably lower than 1.0 p.p.m. and seldom, if ever, higher than 5.0 p.p.m.

Barley (Hannchen)

The effect of prolonged sulphur dioxide treatment with average concentrations between 0.27 and 0.34 p.p.m. on the total sulphur and nitrogen (protein) content of barley leaves is shown in Table IX. After about 154 hours' treatment, coincident with the appearance of a considerable amount of acute and chlorotic markings, there was a reduction in protein content. However the plants appeared capable of recovering from this chlorotic condition when the fumigation was discontinued. Samples collected nine days after treatment for 214 hr. with 0.27 p.p.m. showed a normal protein content. There was a small decrease in the sugar and polysaccharides and a slight increase in the protein of the mature grain (cf. Table X).

The effect of various treatments on the composition of barley grain at maturity is shown in Table XI, which summarizes the results of 32 experiments. In the experiments in Series I with average concentrations of 1.0 p.p.m. or less, where the extent of leaf injury was not greater than 5%, there are no significant differences in the protein and carbohydrate contents between the fumigated and control barley plots. In Series II, treatments with higher and more injurious sulphur dioxide concentrations have resulted in a significant decrease in the content of acid-hydrolyzable polysaccharides. A significant correlation is found between the percentage of leaf injury and reduction in polysaccharide content of the grain. The latter is more readily affected by injurious sulphur dioxide treatments than the protein content.

TABLE X
EFFECT OF SULPHUR DIOXIDE TREATMENT ON MATURE BARLEY GRAIN

Sulphur dioxide treatment			Total sulphur, %	Nitrogen, %	Reducing sugars & sucrose, %	Acid-hydrolyzable polysaccharides, %
Concentration, p.p.m.	Duration, hr.	Remarks				
0.27	214	24 intermittent treatments over period of about 40 days	0.097	2.10	1.61	59.2
Control			0.099	1.98	2.09	61.5

TABLE XI
COMPARATIVE AVERAGE ANALYSES OF BARLEY GRAIN FROM FUMIGATED AND CONTROL PLOTS AT MATURITY

Number of experiments	Averages for fumigated barley plots							Averages for control barley plots		
	Suphur dioxide treatment		Age of plants at start of treatment, days	Leaf injury, %	Nitrogen, %	Reducing sugars and sucrose, %	Starch*, %	Nitrogen, %	Reducing sugars and sucrose, %	Starch*, %
	Concentration, p.p.m.	Duration, hr.								
SERIES I										
3	0.276	96.9	24-40	0	2.06	2.12	61.3	2.24	2.20	62.0
6	0.517	10.5	26-32	2	2.48	2.22	62.3	2.36	2.47	62.5
8	0.965	14.5	51-57	2	2.05	2.24	60.3	2.03	2.37	60.9
3	1.04	7.4	24-39	5	2.21	1.97	63.9	2.23	2.29	64.0
SERIES II										
6	1.34	15.6	20-37	24	2.61	2.36	60.5	2.46	2.34	62.6
4	3.25	16.2	54-56	16	2.37	2.62	59.7	2.39	2.73	62.4
2	2.24) 5.07)	3.0) 3.5)	19) 41)	16) 70)	2.04	2.44	51.9	2.31	2.41	58.8

Mean difference in starch content between control and fumigated plots in Series II=3.1%, $t=2.41$, $n=22$, P approximately equal to 0.02.

Correlation between leaf injury and reduction in starch content of grain. (Series I and II). $r=+0.838$, P less than 0.02.

* Acid-hydrolyzable polysaccharides.

Winter Wheat (Gold Coin)

In May, 1935, several experiments were carried out on winter wheat which had been planted in the late autumn of 1934. The sulphur dioxide treatments consisted of higher average concentrations than are usually found in the Trail area except for short intervals at points relatively close to the smelter. The sulphur dioxide and chemical data are given in Table XII. In the first experiment the gas was maintained continuously over the plants for 72 hr. at an average concentration of 0.42 p.p.m. In the other two experiments the treatments were intermittent in character and extended over a period of 12 days for the 110 hr. treatment and 14 days for the 138 hr. treatment. Sulphur dioxide markings appeared on the leaves of the plants in each case, but even in the last experiment the extent of the injury was not over a few per cent. Wheat is more resistant to sulphur dioxide than barley of the same age.

Although the gas treatments resulted in a considerable increase in the total sulphur content of the wheat leaves, no significant differences were found in the total nitrogen content on either a dry or green weight basis. The average sugar content of the fumigated leaves is lower than that of the controls, although the difference is not statistically significant. However, a small but significant increase is shown in the amount of alcohol-insoluble residue in the fumigated leaves. This is due in part at least to the increase in sulphur and decrease in sugar content.

The absorption of sulphur by stems is extremely small compared with that by leaves. This was found to be true not only of wheat but also of barley and alfalfa. It is in fact due to this comparative lack of absorption that stems of plants are rarely found to be marked by sulphur dioxide.

Alfalfa (Grimm)

A considerable number of alfalfa plots were treated with low concentrations of sulphur dioxide for prolonged periods during the growing seasons of 1935 and 1936. The fumigation and chemical data for a series of experiments with average concentrations between 0.10 and 0.40 p.p.m. are shown in Table XIII. In most of these experiments there were either no markings found on the leaves or else the injury was of a negligible character. In Plots C-17 and A-1, however, the leaf destruction was about 8%. With the exception of Plot A-1 no significant differences are apparent in either moisture, protein or acid-hydrolyzable polysaccharides plus sugars in the leaves of the fumigated plots in comparison with the controls. However the roots in Plot C-17 treated with 0.37 p.p.m. for 378 hr. show a considerable difference in the distribution of sucrose and acid-hydrolyzable polysaccharides, although the total of the two is not appreciably lower than that of the control.

TABLE XII
COMPARISON OF FUMIGATED AND UNTREATED LEAVES OF WINTER WHEAT. EXPERIMENTS PERFORMED IN MAY, 1935

Fumigated plants										Control plants					
Sulphur dioxide treatment		Age of plants from date of first spring growth, days	Leaf number in relation to plant	Mois- ture, %	Total nitro- gen, %	Total nitro- gen, (Green wt. basis), %	Reduc- ing sugars plus sucrose, %	Alcohol- insolu- ble re- sidue, %	Mois- ture, %	Total sulphur, %	Total nitro- gen, %	Total nitro- gen, (Green wt. basis), %	Reduc- ing sugars plus sucrose, %	Alcohol- insolu- ble re- sidue, %	
Concen- tration, p.p.m.	Dura- tion, hr.														
0.42	72	27	4	78.9	0.64	3.48	0.73		76.7	0.49	3.33	0.78			
			5	77.6	0.72	4.44	0.99		76.3	0.47	4.16	0.99			
			6	75.0	0.85	4.68	1.17	68.0	73.9	0.45	4.39	1.15	10.36	63.9	
			7	75.6	0.86			74.7	75.1	0.37	4.61	1.15	9.60	67.6	
0.47	110	30	4	82.2	0.80	3.65	0.65		81.5	0.52	3.47	0.64			
			5	80.8	0.94	4.44	0.85		79.6	0.56	4.46	0.91			
			6	78.7	1.04	5.04	1.07	74.0	77.4	0.59	5.13	1.16	3.64	70.8	
			7	77.5	0.88	5.29	1.19	77.0	76.3	0.55	5.30	1.26	3.73	72.4	
0.11	30.0	50	5	69.3	0.63	2.82	0.87		74.4	0.51	2.95	0.76			
0.405	102.5		6	71.7	0.79	3.63	1.03		74.2	0.46	3.94	1.02			
1.04	5.5		7	70.4	0.84	4.05	1.20	67.6	72.1	0.47	4.34	1.21	7.74	68.1	
			8	69.4	0.33	4.29	1.31	75.2	69.9	0.51	4.44	1.34	10.37	73.1	
			Stems	73.4	0.25	1.44	0.38		74.4	0.19	1.33	0.34			
			Heads	72.2	0.22	1.96	0.54		72.4	0.22	2.09	0.58			
Averages for leaf analyses				75.6	0.82	4.16	1.01	6.91	72.7	0.495	4.21	1.03	7.57	69.3	

Mean difference for alcohol-insoluble residue, 3.4, $t=3.27$, $n=5$, and $P=\text{approx. } 0.02$.

Further data bearing on the composition of alfalfa leaves after treatment with sulphur dioxide are given in Table XIV. The results obtained with the low-concentration treatments indicate that there was no adverse effect on the content of the various nitrogen fractions, sugars or polysaccharides in the leaves and serve to confirm the data in Table XIII obtained the previous year. Even in treatments with concentrations as high as 0.60 p.p.m. where some markings appeared on the leaves there was no significant change in the chemical composition of the leaves, apart from their higher sulphur content, either within a few days after the experiment or some time subsequently.

A considerable effect on the chemical composition of the leaves was manifest however after treatment with 2.92 p.p.m. The samples were collected two days after fumigation, the leaves being divided into those totally injured by the gas and those apparently of a normal green color. The injured leaves, which were bleached almost to an ivory white, had by this time lost most of their moisture content and were quite deficient in sucrose and acid-hydrolyzable polysaccharides. There was a decrease in alcohol-soluble nitrogen but a considerable increase in insoluble nitrogen. The apparently normal fumigated leaves were not appreciably different from the controls in regard to their content of moisture and nitrogen but there was a considerable decrease in the amount of polysaccharides. The sucrose content was normal.

The decrease in carbohydrates which occurs when plants are subjected to such high concentrations is accompanied by a more fundamental change in physiological behavior involving the photosynthetic mechanism, as will be shown in studies on carbon dioxide assimilation which are discussed in Chapter XV.

The moisture, total sulphur and protein contents of alfalfa leaves in some miscellaneous experiments with high concentrations are given in Table XV. Leaves treated under these conditions, if appreciably injured, show apparently a considerably higher nitrogen content on a dry basis owing to the decrease in moisture and carbohydrate contents. If, however, the injury is insufficient to affect the moisture content, the nitrogen content remains unchanged.

ABSORPTION OF SULPHUR DIOXIDE BY ALFALFA IN RELATION TO LEAF INJURY

It has been shown in preceding chapters that plants may absorb a given amount of gas without injurious effects if the gas is taken up slowly, whereas the same amount is extremely toxic to the tissues if absorbed within a short time period. According to Thomas and Hill (7) the absorption of sulphur dioxide by alfalfa leaves is made up of three principal variables; the time, the concentration, and an absorption factor which is a measure of the activity

TABLE XIV

COMPOSITION OF ALFALFA LEAVES AFTER TREATMENT WITH SULPHUR DIOXIDE, 1936 DATA

Expressed as per cent

Plot no.	Sulphur dioxide treatment		Moisture	Total sulphur	Alcohol-soluble nitrogen	Organic and ammoniacal nitrogen	Insoluble nitrogen, (by difference)	Reducing sugars	Sucrose	Acid-hydrolyzable polysaccharides	Acid-hydrolyzable polysaccharides plus sugars
	Concentration, p.p.m.	Duration, hr.									
C-10	0.15	166	76.2	1.21	0.99	5.02	4.03	1.14	2.70	15.17	19.01
C-11+			76.1	0.71	0.99	5.17	4.18	1.27	2.45	15.23	18.95
C-9x			72.4	0.64	0.93	4.98	4.05	1.12	2.20	15.93	19.25
I-12	0.15	525	83.2	2.14	1.35	5.34	3.99				
I-11+			81.7	0.80	1.12	5.24	4.12				
G-16	(0.22-0.25 (0.43-0.50 (0.60	15 12¾ 1½	82.0	1.16	1.38	5.47	4.09				
H-17+			82.4	0.85	1.41	5.48	4.07				
F-2	(0.12-0.30 (0.36-0.61	44 36	79.3	1.46	0.99	5.59	4.60	1.62	2.40	7.16	11.18
E-1+			79.1	0.83	0.91	5.48	4.57	1.28	2.23	8.38	11.89
E-2x			76.0	0.86	0.68	4.87	4.19	1.00	1.91	11.75	14.66
B-1	0.03-0.28 0.30-0.75	217 11½	79.5	1.43	0.96	5.40	4.44	1.13	2.64	9.26	13.03
A-2+			78.1	0.65	0.70	5.14	4.44	1.11	2.87	10.83	14.81
Average of fumigated plots			80.0	1.48	1.13	5.36	4.23				14.41
Average of cabinet control plots			79.5	0.77	1.03	5.30	4.27				15.22
H-4*	0.34	12	64.5	0.79	0.76	4.06	3.30	1.99	2.30	9.68	13.97
H-5+			58.5	0.69	0.78	3.82	3.04	1.55	2.18	7.59	11.32
G-8**	0.34	70½	61.2	0.94	0.83	3.93	3.10	1.57	2.36	8.97	12.90
H-9**	0.62	67	64.2	1.19	0.76	4.12	3.36	1.89	2.68	8.80	13.37
G-7+			59.7	0.78	0.93	4.25	3.32	1.31	2.45	7.47	11.23
D-7	2.92	4	32.1	1.28	0.59	5.97	5.38	2.13	0.78	8.41	11.32
D-7	2.92	4	79.1	0.95	0.97	5.44	4.47	2.23	2.63	11.30	16.16
C-7+			76.5	0.77	0.90	5.32	4.42	1.34	2.47	15.55	19.36

+ Cabinet control.

x Field control.

* Samples collected 28 days after treatment.

** Samples collected 24 days after treatment.

TABLE XV
EFFECT OF HIGH CONCENTRATIONS OF SULPHUR DIOXIDE ON TOTAL
SULPHUR AND NITROGEN CONTENT OF ALFALFA LEAVES

Plot no.	Sulphur dioxide treatment		Percentage injured leaves in sample	Moisture		Total sulphur		Organic and ammoniacal nitrogen	
	Concentration, p.p.m.	Duration, hr.		Fumigated	Control	Fumigated	Control	Fumigated	Control
B-6	1.46	2.25	6	—	—	1.01	0.82	5.48	5.41
Y-6	1.50	26.5	0	81.3	81.5	0.90	0.72	4.83	4.96
Y-6	1.50	26.5	100	68.4	81.5	0.97	0.72	5.84	4.96
D-13	2.30 2.65	1.0 1.0		79.6	79.4	0.83	0.57	6.26	6.10
I-9	5.0	1.0	57	79.3	83.4	0.79	0.67	6.28	6.28
A-15	6.22	0.4	100	—	—	0.83	0.72	5.56	5.19
A-15	6.22	0.4	High	69.4	79.1	0.80	0.67	5.06	4.74

of the plant and is dependent upon various internal and external conditions related to its environment. The extent to which the absorption factor may be influenced under certain environmental conditions has been discussed in Chapter XI.

Thomas and Hill (7) have shown from experiments with high concentrations of gas for short exposures of 60 to 100 min. or less, that there is a linear relation between the percentage of leaf area of the alfalfa that is destroyed and the amount of sulphur dioxide absorbed in parts per million of dry leaf tissue. The absorption relations which were determined by gas analysis of the air in the cabinets, or the sulphur content of the leaves, are based on the assumption that the gas is present in the tissues mainly as sulphur dioxide, although no direct proof by chemical analysis was attempted.

The actual quantities of sulphur dioxide or sulphurous acid accumulated by alfalfa leaves, during treatment for prolonged periods at low concentrations and short periods at high concentrations in experiments at Summerland, are given in Table XVI. At the low concentrations, in the absence of leaf injury, there is no measurable amount of sulphurous acid present even after prolonged exposure. The gas is accumulated in the leaves almost entirely as sulphate, *i.e.*, the rate of absorption is about equal to the rate of oxidation. As the concentration is increased, however, an appreciable amount of sulphur dioxide tends to accumulate in the unoxidized form, and there is a high degree of correlation between this and the extent of leaf injury. The correlation coefficient for these data in Table XVI is +0.87 if the sulphur dioxide absorbed, as such, is calculated in parts per million of dry leaf tissue.

RELATION BETWEEN ABSORPTION AND TIME OF EXPOSURE

The relation between the amount of sulphur dioxide absorbed (y), expressed as per cent of the dry tissue, and time of exposure (x) for two series of experiments at average concentrations of 0.153 p.p.m. and 0.446 p.p.m. is shown in Table XVII. In the first series of experiments at an average concentration of 0.153 p.p.m. there was either no injury produced or the extent of the markings was so slight as to be negligible. In the second series an appreciable number of marked leaves were present only after some of the longer treatments at concentrations of 0.40, 0.62, and 0.71 p.p.m.

The amount of sulphur dioxide absorbed at these low concentrations increases linearly with time of exposure, the gas being stored in the leaves almost entirely as sulphate. At concentrations of 0.15 p.p.m. or lower this relation holds for continuous exposure throughout the growth of a crop of alfalfa. At higher concentrations it is valid only up to the point of incipient leaf injury. The results indicate that the amount of sulphur accumulated is greater the lower the rate of absorption.

TABLE XVI
ABSORPTION OF SULPHUR DIOXIDE BY FUMIGATED ALFALFA LEAVES

Sulphur dioxide treatment		Leaf injury, %	Analyses expressed as % sulphur on dry leaf tissue				
Concentration, p.p.m.	Duration, hr.		Total sulphur		Absorption of sulphurous acid, %	Soluble sulphates	
			Before treatment, %	After treatment, %	Absorption, %	Before treatment, %	After treatment, %
0.10	504.0	0	0.60	1.28	0.68	—	—
0.22	35.4	0	0.43	0.70	0.27	0.30	0.49
0.22	121.5	trace	0.46	1.15	0.69	0.31	0.93
0.24	74.0	0	—	—	—	—	—
0.40	17.0	0	0.34	0.63	0.29	0.20	0.47
0.40	171.0	8*	0.67	1.90	1.23	0.29	1.53
1.68	2.0	4	—	—	—	—	—
1.62	2.0	7	—	—	—	—	—
2.28	2.0	20	—	—	—	—	—
2.47	2.0	30	—	—	—	—	—
3.00	2.75	36	0.65	0.93	0.28	—	—
3.15	3.0	25	0.69	0.91	0.22	0.35	0.48
3.20	1.0	18	0.65	0.81	0.16	—	—
3.46	1.0	13	0.65	0.82	0.17	—	—

* Leaves in this experiment show mainly the chlorotic type of injury.

TABLE XVII
RELATION BETWEEN TIME OF EXPOSURE AND ABSORPTION OF
SULPHUR DIOXIDE BY ALFALFA LEAVES

Concentration of sulphur dioxide, p.p.m.	Time of exposure, hr. (x)	Absorption of sulphur dioxide in dry leaf tissue, % (y)	
0.17	60	0.54	Equation of curve, $y = 0.4672 + 0.00341x$ correlation coefficient, $r = + 0.9407$ $S(y) = 0.2469$
0.17	95	0.52	
0.17	112	0.70	
0.18	136	0.98	
0.15	166	1.00	
0.15	167	1.40	
0.12	240	1.54	
0.15	525	2.68	
0.16	562	2.16	
0.11	602	2.24	
Average 0.153	266.5	1.376	
0.36	8	0.24	Equation of curve, $y = -0.0394 + 0.01535x$ correlation coefficient, $r = + 0.942$ $S(y) = 0.2095$
0.34	12	0.20	
0.56	16	0.58	
0.50	37	0.80	
0.35	48	0.88	
0.62	67	0.82	
0.38	72	0.94	
0.71	72	1.40	
0.24	160	1.52	
0.40	171	2.40	
Average 0.446	66.3	0.978	

Discussion

Mild treatment of plants, under conditions of either intermittent or continuous exposure throughout their period of growth, at low concentrations insufficient to produce leaf markings, causes an abnormal increase in sulphur content but no other change in composition. The sulphur is stored mainly as sulphate, a form that is non-toxic if the limit of tolerance is not exceeded. The tolerance limit, although not definitely determined by this work, has nevertheless been shown to be sufficiently high to enable the leaves to accumulate sulphur in amounts three or four times greater than normal without adverse effects at low gas concentrations.

The limit of tolerance is higher for alfalfa than for barley or wheat, and probably varies not only with the plant species but also with the soil type. If, during exposure to this gas, the absorbed sulphur dioxide is oxidized entirely to sulphuric acid at the same rate as it is absorbed and the latter neutralized as rapidly as formed, the process of accumulation is governed by the amount of bases available in the plant system. A similar view has been

expressed by Thomas and Hill (7). On the other hand, when the rate of absorption exceeds the rates of oxidation and neutralization, free acid is formed in the tissues. The quantity of free sulphuric acid which may be tolerated by plants is unknown, but very small amounts of free sulphurous acid may cause injury correlated with an alteration of the carbohydrate-protein balance.

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CHAPTER XV

CARBON DIOXIDE ASSIMILATION AND RESPIRATION OF ALFALFA UNDER INFLUENCE OF SULPHUR DIOXIDE

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Introduction and Literature Review

The absorption of carbon dioxide and its combination with water as a step in the synthesis of carbohydrates is the fundamental process of living plants, the energy absorbed from sunlight being transformed into chemical energy during this synthesis. The energy thereby stored in the plant is released during respiration for the production of other complex substances. These fundamental reactions of photosynthesis and respiration, which occur throughout the life of the plant, afford a most sensitive indicator of growth. A study of the rate of carbon dioxide assimilation and respiration is therefore of the utmost importance in the evaluation of the effect on vegetation of concentrations of sulphur dioxide commonly found in the atmosphere.

Some indication of a specific action of sulphur dioxide in high concentrations on the photosynthetic mechanism of plants may be gleaned from a consideration of the behavior of susceptible species in the presence and absence of light. The importance of light in this connection has already been discussed in Chapter XI, and the effect of this factor cannot be entirely accounted for by its influence on stomatal opening and rate of absorption of gas. It is known that in water plants such as *Elodea canadensis*, which take up sulphur dioxide through the epidermis, since stomata are absent, much higher concentrations of gas are required for injury in darkness than in light (6). Furthermore, it has been shown in Chapter IX that conifers are very susceptible to sulphur dioxide during periods of active growth, *i.e.*, in the spring and early summer, when carbon dioxide assimilation is at a maximum. Their resistance to gas increases markedly, however, in the late summer and fall, even though the leaves are still capable of absorbing this gas. Similar maximum susceptibility when the environmental factors are most favorable for carbon dioxide assimilation is also noted in other plants. Plant organs which do not contain chlorophyll, *e.g.*, flower parts, are noticeably more resistant to sulphur dioxide. This is also true of buds and cotyledons and very young leaves in which the chlorophyll has not been fully elaborated. Furthermore, in the case of variegated leaves it has been noted that the white portions may remain alive and turgid after sulphur dioxide treatment, while the green parts show the characteristic discolorations indicative of sulphur dioxide injury (3, 4). Apparently, therefore, sulphur dioxide in sufficient concentration is capable of acting specifically on the chlorophyll mechanism when carbon dioxide assimilation is in evidence.

The reduction in carbon dioxide assimilation of plants under the influence of sulphur dioxide was first demonstrated by Wieler (12, 13) in experiments on

gaseous exchange of potted plants. Wieler claimed a noticeable reduction in assimilation even when the leaves were treated with concentrations which did not result in discolorations. In some of his experiments the plants did not react immediately, but a decrease in assimilation became manifest after the fumigation had been stopped. More recently Wieler (14) has extended his investigations to the effect of sulphur dioxide on the carbon dioxide assimilation of conifers and broad-leaved species, including spruce, pine, birch, ash, red beech and linden. The gas concentrations used varied from about 1.0 to 10.0 p.p.m. Injury to the leaves, accompanied by a decrease in the carbon dioxide assimilation, was manifest in nearly all his experiments. However, the calculated percentage reduction in assimilation is based on the unjustifiable assumption that the rate of photosynthesis remains constant throughout the growing season for a given species, whereas in fact the assimilation is much higher in early summer than in the autumn. During the period of several months covered by each experiment, the rate of assimilation of the fumigated plants was determined only during three or four four-hour intervals. There are no data indicating what the rate would have been at the same time on comparable specimens of unfumigated material. Therefore the exact effect of sulphur dioxide on the carbon dioxide assimilation, in Wieler's experiments, remains in doubt.

According to Stoklasa (7) sulphur dioxide hinders the photosynthetic assimilation of carbon dioxide by inducing an abnormal reduction in starch and other carbohydrates. Kurt Noack (4), in experiments on the water moss, *Fontinalis*, found a decrease in carbon dioxide assimilation under constant light intensity and at a temperature of 10°C., after treatment for 24 hr. in darkness with 0.0005% sodium bisulphite solution. More recently Wehner (11) has demonstrated a stimulating effect on the assimilation of *Fontinalis* and some land plants, such as clover and tobacco, in sulphurous acid solutions in a dilution of $5 \cdot 10^{-5}$ to $10^{-6}\%$. More dilute concentrations were without effect. With *Fontinalis* a maximum stimulation of 150% of normal was obtained with a concentration of $5 \cdot 10^{-6}\%$. Kurt Noack (5) has also considered the possibility that sulphur dioxide exerts a stimulating effect on the carbon dioxide assimilation of plants, when the gas is present in sufficiently dilute concentration.

In 1930 Heilbronn (2), in an investigation on the influence of industrial air on assimilation by plants, set up two smoke chambers under equal carbon dioxide concentrations. In one chamber the plants were treated with a normal industrial atmosphere, while in the other similar plants were subjected to purified air. He found evidence of greater and more rapid growth in the plant chamber containing industrial air, and concludes that industrial gases have a stimulating action. However, Bredemann (1) has criticized Heilbronn's experiments because of the fact that the humidity in the two chambers was greatly different, and also on other grounds (1).

The physiological action of sulphur dioxide in relation to smoke damage was reviewed by Bredemann in 1932 (1). In this review, Bredemann states that

respiration is not as readily disturbed by sulphur dioxide as the carbon dioxide assimilation. Some substances toxic to plants in certain concentrations actually increase the intensity of respiration. Wieler (12) has reported that in his experiments the respiration is sometimes decreased, and at other times increased, during fumigation. Stoklasa (7, p. 239) reports a considerable reduction in respiration of spruce trees treated with abnormally high concentrations—0.075 to 3.5% sulphur dioxide by volume. Such experiments dealing with unusually high concentrations, which result in speedy death of the plant cells, are of little value in dealing with the practical problem of damage caused by those concentrations of sulphur dioxide normally found in the atmosphere.

Thomas and Hill (10) in 1937 published the results of an outstanding investigation on the relation of sulphur dioxide in the atmosphere to photosynthesis and respiration of alfalfa. The experiments were undertaken primarily to determine whether concentrations of sulphur dioxide which do not produce any visible injury to the plant, whether applied as high concentrations of short duration, low intermittent concentrations, or as continuous fumigations throughout the life of the plant, could cause injury to the protoplasm or any other plant structure. The effects of the gas treatments were determined by measuring the rate of photosynthesis and respiration of a treated plot of alfalfa in comparison with a similar untreated plot. The measurements extended over a period of from several days before the fumigations were begun to several days after they were discontinued. The observations on the effects of the fumigation were supplemented by chemical analyses of the plant material for sulphur and chlorophyll.

It was found that short fumigations with high concentrations of sulphur dioxide, which were discontinued before an appreciable amount of leaf destruction was produced, caused a large reduction in the rate of photosynthesis during fumigation, but the photosynthesis began to increase within an hour after the treatment. The effect of such fumigations could be observed in a somewhat lowered rate of apparent assimilation for about two days after the treatment. Thereafter the rate was normal or greater than normal. A number of short fumigations, with concentrations ranging from 0.7 to 1.26 p.p.m., each caused a definite decrease in the photosynthetic level. Immediately after the fumigations were discontinued however, the activity rose to a normal or greater than normal level, so that when the total assimilation was calculated the decreased assimilation that had occurred during the fumigation was largely counterbalanced by increased assimilation after the fumigation was discontinued. Three long continuous fumigations in 1935 showed that no effect of the fumigation occurred with 0.24 p.p.m. for about 3 days, with 0.19 p.p.m. for 11 days, and with 0.14 p.p.m. for at least 39 days. The data even suggest a slight stimulation of apparent assimilation during these periods. The continued application of the higher concentrations caused a gradual reduction in the photosynthetic level of the treated plot, with attendant visible markings of the

leaves and premature shedding of the older leaves. The reduced rates of photosynthesis were paralleled by reduced amounts of functioning leaf tissue.

The experiments to be described in this chapter on the carbon dioxide exchange of alfalfa were carried out at the Dominion Experimental Station, Summerland, B.C. during the growing seasons of 1935, 1936 and 1937, on field plots grown under irrigation. The authors are indebted to Dr. Thomas, of the Department of Agricultural Research of the American Smelting and Refining Co., Salt Lake City, Utah, for the design of the carbon dioxide analytical autometers used in this investigation. These ingenious machines rendered it possible to determine continuously the rate of carbon dioxide exchange with alfalfa grown in plant chambers in the field. The effect of sulphur dioxide treatment was shown not only by comparing the rates of photosynthesis and respiration of plants before and after fumigation, but also by comparison of the rates with those for an equal number of plants in a similar control plot.

The work was undertaken to determine whether such concentrations as were commonly found to occur in the atmosphere of the Trail-Northport area and other industrial areas (see Chapter II) exert an injurious effect on the photosynthesis and respiration of alfalfa, one of the species most sensitive to sulphur dioxide. Experiments were made with high concentrations of short duration and with lower concentrations applied intermittently or continuously during the growth of the plant, the gas conditions in many of these experiments being such that no visible injury was apparent to the plant. The theory of "invisible injury" was therefore investigated more thoroughly than was possible in the yield studies. The data obtained aid materially in answering the question whether fumigations which do not result in visible injury to the leaf surface may or may not cause injury to the living cell.

Preliminary experiments showed that the carbon dioxide content of the atmosphere itself was not constant but within certain narrow limits showed a diurnal rhythm, the highest content being recorded at night and the lowest in the afternoon. A seasonal variation in the carbon dioxide content of the atmosphere was also noted, the carbon dioxide content being higher in the early spring and late fall than in the summer. Preliminary experiments on wheat and alfalfa plants indicated very little assimilation in static air containing as low as 100 p.p.m. of carbon dioxide, and a marked reduction in respiration when the carbon dioxide concentration was in excess of about 1,500 p.p.m. The experiments were therefore carried out under conditions whereby sufficient air movement was maintained in the cabinet to provide for the normal requirements of photosynthesis and respiration. Extreme care was taken to maintain the same rate of air delivery to the cabinets of both the fumigated and control plots in a given experiment. During the day the air volume was delivered at a rate of 2,750 to 4,000 litres per min. whereas at night the air volume was reduced to about 1,000 litres per min.

The maximum absorption of carbon dioxide by the plants during photosynthesis was usually 15-18% at an air velocity of about 4,000 litres per min. At lower air velocities correspondingly higher differences were recorded between the carbon dioxide content of the air entering and that of the air leaving the cabinet, and within certain limits these differences were found to be proportional to the air velocity. The conductivity method used in these experiments was sufficiently precise to detect a difference in concentration corresponding to about 1 p.p.m. or about 0.3% of the concentration of carbon dioxide in the air entering the cabinet.

The Effect of Sulphur Dioxide on Carbon Dioxide Exchange

The effect of sulphur dioxide on the carbon dioxide exchange is demonstrated by the results obtained in the following series of experiments carried out on specially prepared plots of alfalfa. The experiments are described in order of decreasing sulphur dioxide concentrations beginning with short fumigations with high concentrations and progressing downward to long-continued fumigations with non-toxic concentrations. Chemical and agronomic data have been presented in earlier chapters.

Effect of a Short Treatment with 6.22 p.p.m.

In a short treatment with 6.22 p.p.m. sulphur dioxide from 10.00 to 10.25 a.m. on July 16, 1935, the effect of the high gas concentration was immediately noticeable on the rate of photosynthesis. The carbon dioxide data in Table I indicate a comparable rate of assimilation prior to the gas treatment by the plants in Plots A-15 and A-16. As soon as the sulphur dioxide gas was admitted to the cabinet over Plot A-15, the apparent carbon dioxide assimilation dropped rapidly within a few minutes and then passed the compensation point, respiration predominating. The rate of assimilation during the period 10.00 to 11.00 a.m. was 8.08 gm. for the control plot and -3.65 gm. for the fumigated plot.

TABLE I
EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Continuous treatment for 25 min. at 6.22 p.p.m

Date 1935	SO ₂ treatment		CO ₂ assimilated, gm. per day.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot A-15	Control plot A-16
July 14			34.61	35.23
16	10.00-10.25 a.m.	6.22	35.60	60.81
17			46.44	90.59
Total assimilation, July 14 to 17 -----			116.65	186.63

For the remainder of the day the assimilation values for Plot A-15 were considerably lower than those for the control plot.

The treatment produced markings on 89% of the leaves, the plants wilting perceptibly during the period of application of the gas and for about an hour afterwards. Injury was visible on the top leaves 12 min. after the application of the sulphur dioxide gas, and the wilting symptoms were also evident at this time. The sepals on most of the flowers were injured and the petals of some plants were slightly bleached. The buds, however, were not injured.

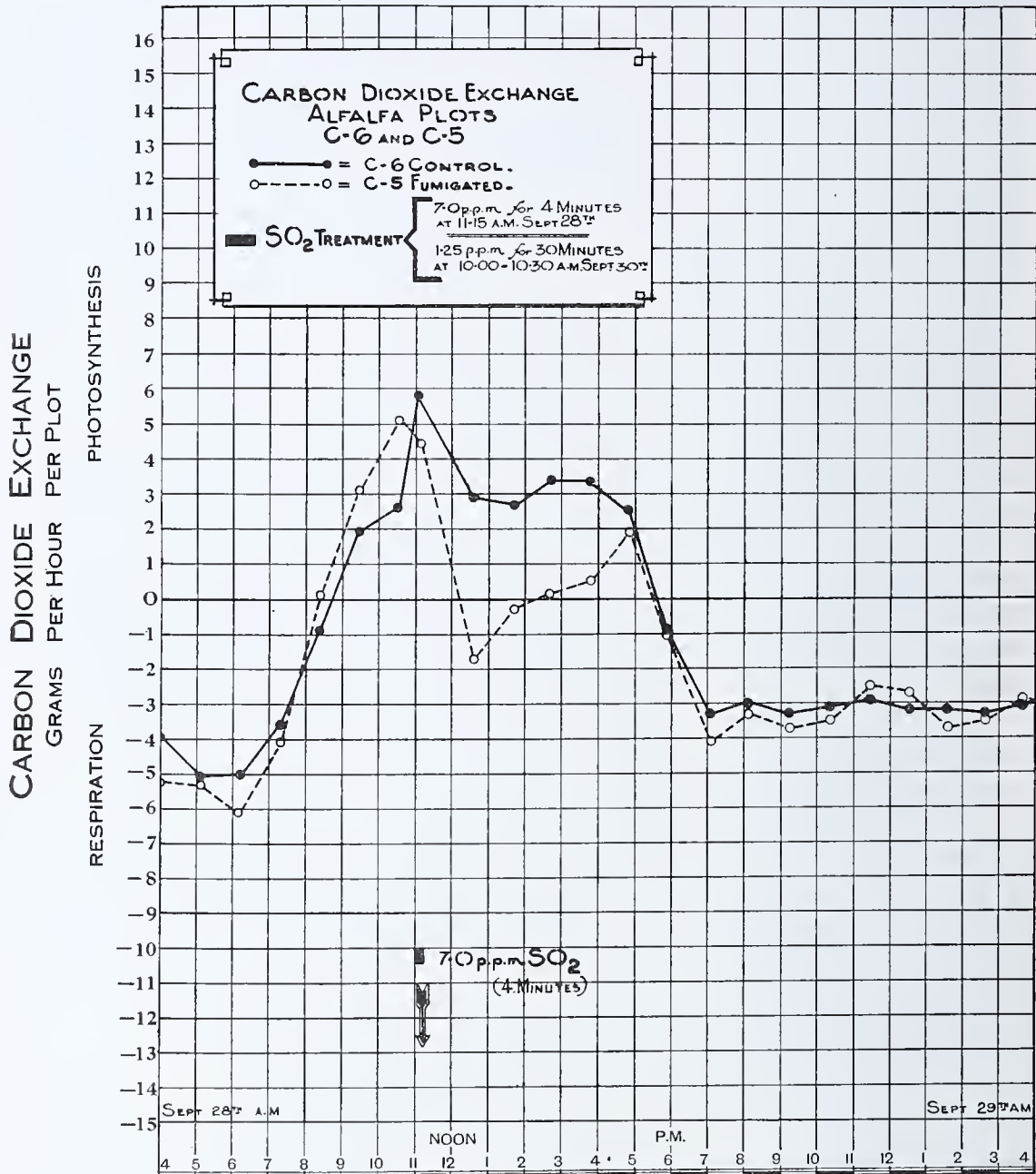


FIG. 1.

Effect of Intermittent Treatments of Sulphur Dioxide with 7.00 and 1.25 p.p.m.

The results of two brief treatments with high concentrations carried out without visibly injuring the leaf tissue of the plants are shown in Table II and illustrated by the curves in Figs. 1 - 3.

In the first treatment an immediate effect was noted on the rate of photosynthesis (see Fig. 1). The treated plants apparently ceased to assimilate carbon dioxide, and for several hours the readings of gaseous exchange indicated that

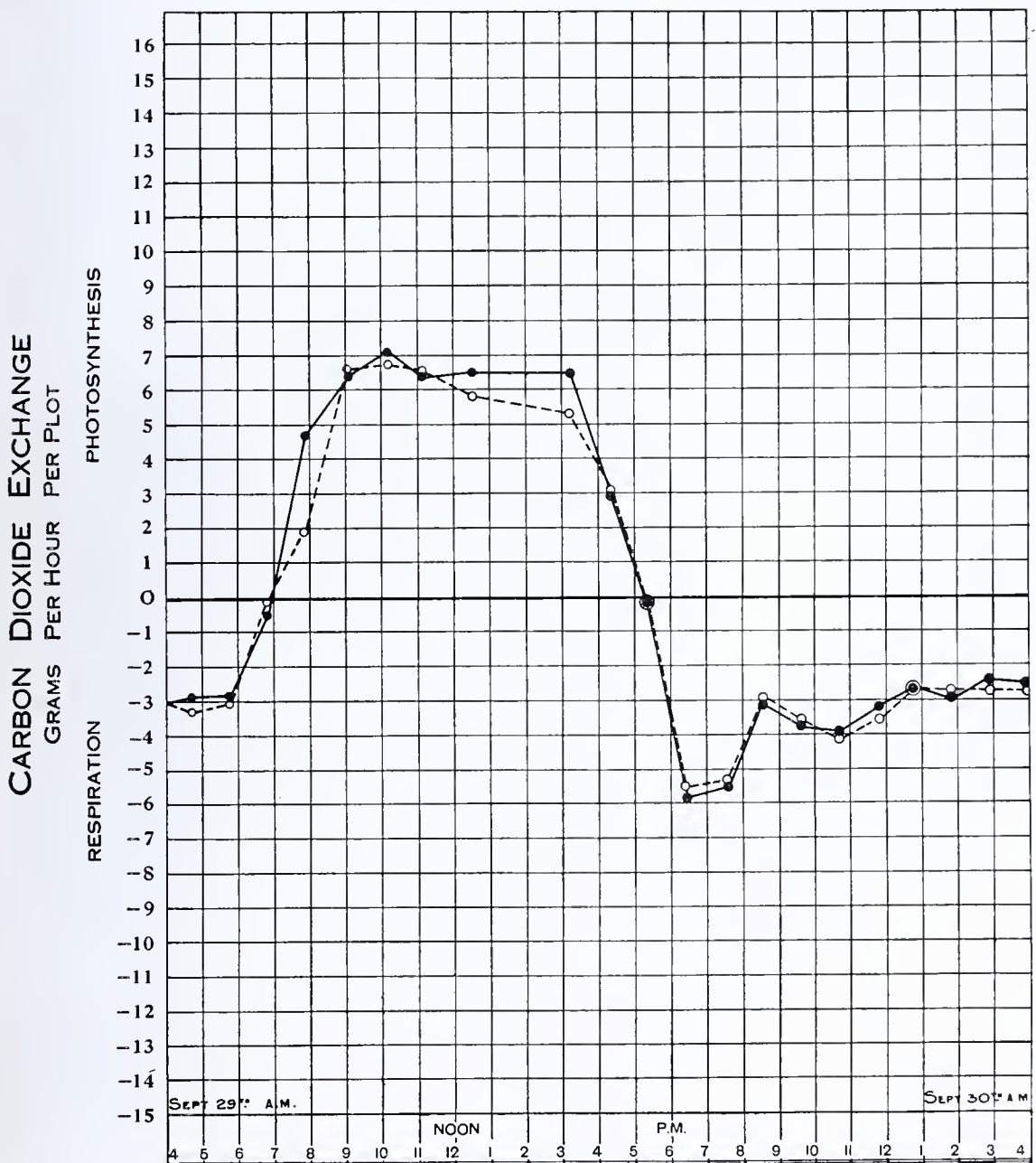


FIG. 2.

respiration was taking place in the fumigated plot. The effect of the gas treatment was evident for the remainder of the afternoon in a reduced amount of carbon dioxide assimilation. From 1.42 to 2.46 p.m. the rate of photosynthesis for C-5 was only 0.07 gm. per hr., whereas that for the control was 3.43 gm. Similarly, during the next hour the rate of photosynthesis for the fumigated plot was 0.51 gm. per hr. whereas the readings for the control plot were 3.34 gm. per hr. There was no substantial difference in the respiration readings, however, during the night of the 28th and the early morning of the 29th. The

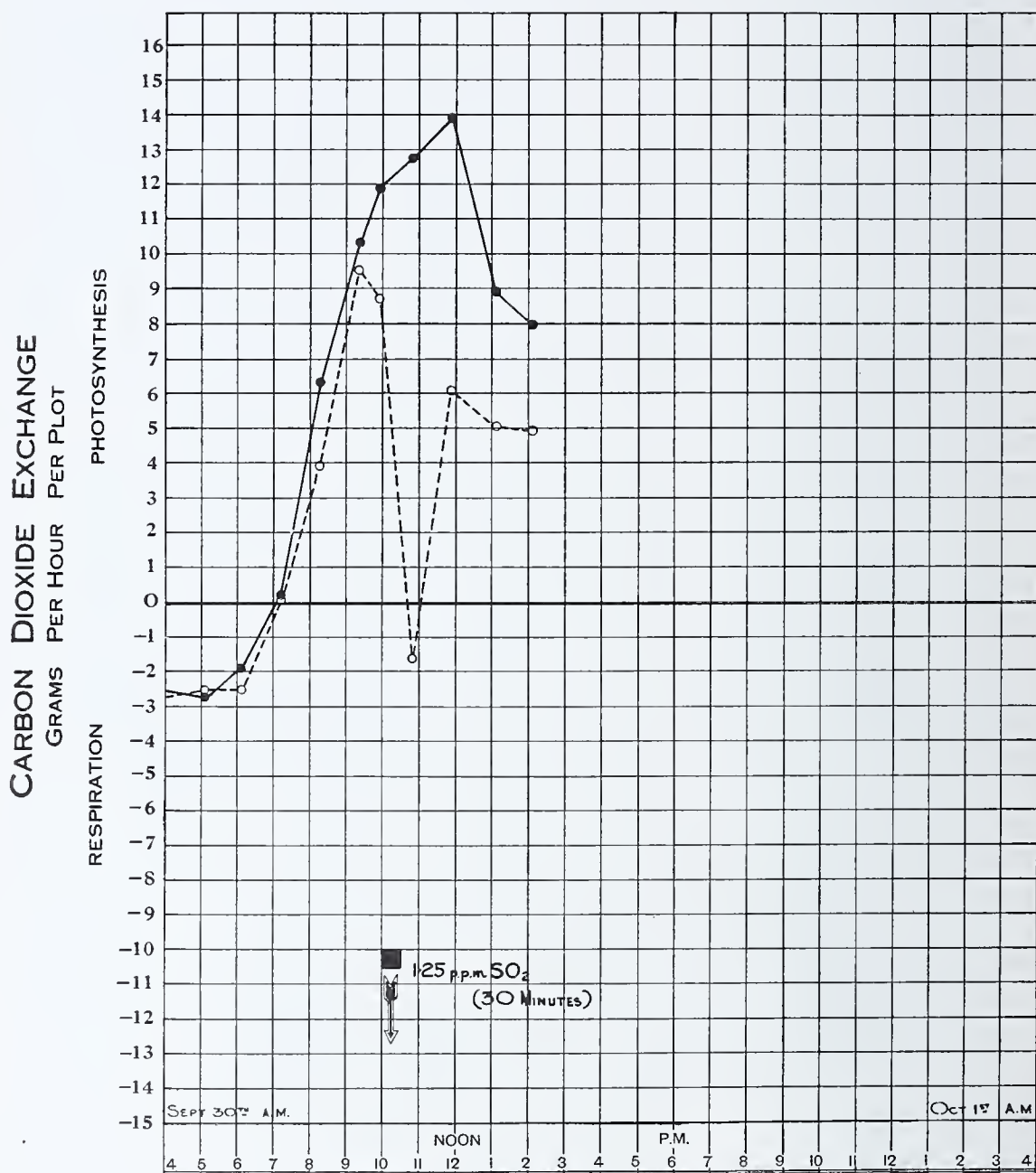


FIG. 3.

TABLE II

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Intermittent treatments with 7.00 and 1.25 p.p.m.

Date 1935	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot C-5	Control plot C-6	Fumigated plot C-5	Control plot C-6
Sept. 27	11.15-11.19 a.m.	7.00			29.45	24.60
28			10.84	19.28	52.12	46.27
29			35.88	40.10	44.10	43.65
30	10.00-10.30 a.m.	1.25	38.53	72.88	14.86	12.40
Total assimilation and respiration, Sept. 27 to 30 -----			85.25	132.26	140.53	126.92
Net assimilation -----			55.28	5.34		

plants in both cabinets began to assimilate carbon dioxide at about 7.00 a.m. on the morning of the 29th (Fig. 2). During the first hour there was a distinct reduction in the rate of photosynthesis on the fumigated plot, but subsequent readings indicated no substantial difference.

In the second short fumigation with 1.25 p.p.m. an effect on the carbon dioxide assimilation was again immediately noticeable during the presence of the gas (Fig. 3). Carbon dioxide assimilation was completely inhibited and 1.60 gm. of carbon dioxide was respired per hour during the time that the control plot assimilated at a rate of 12.77 gm. per hr. The following readings indicated very rapid recovery from this shock.

Intermittent Treatments with 2.30 and 2.65 p.p.m.

The plants in Plot D-13 were fumigated with 2.30 p.p.m. from 10.00 to 11.00 a.m. October 8, 1935, and this was followed by another fumigation of one hour with 2.65 p.p.m. from 9.35 to 10.35 a.m. October 9. These short fumigations with high concentrations resulted in injury to 10.6% of the leaves. The immediate effects on photosynthesis, however, were far greater than could be accounted for by the amount of leaf destruction present on this plot. As shown in Table III the first treatment resulted in a complete inhibition of photosynthesis for the balance of the day, the measurements of carbon dioxide exchange indicating respiration. Similar results were obtained with the second fumigation, the total apparent carbon dioxide assimilation on October 9 being only 2.32 gm. for the fumigated plot compared with 92.29 gm. for the control (see Table III). Some recovery of photosynthesis is noticeable in the days following this treatment, but for October 13, the last day on which carbon dioxide measurements were obtained, the total apparent assimilation was only 27.34 gm. for the fumigated plot compared with 77.77 gm. for the control.

TABLE III
EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Intermittent treatments at 2.30 and 2.65 p.p.m.

Date 1935	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot D-13	Control plot D-16	Fumigated plot D-13	Control plot D-16
Oct. 8	10.00-11.00 a.m.	2.30		39.86	50.22	40.33
9	9.35-10.35 a.m.	2.65	2.32	92.29	36.10	20.85
10			14.42	69.03	29.56	19.73
11			4.49	54.59	86.09	46.56
12			13.69	65.64	51.18	9.99
13			27.34	77.77	2.34	.29
Total assimilation and respiration, Oct. 8 to 13 -----			62.26	399.18	255.49	137.75
Net assimilation, Oct. 8 to 13 -----			-193.23	261.43		

Over the period covered by this experiment the total apparent assimilation by the treated plot amounted to only 15.6% of the control, whereas the night respiration was 185% of the control. The data, therefore, indicate not only a decrease in photosynthesis but a corresponding increase in night respiration, as a result of the sulphur dioxide treatment.

Intermittent Treatments with 1.75 and 0.50 p.p.m.

The results of these experiments are shown in the curves, Figs. 4 - 7, and Tables IV and V. The same control plot C-14 was used in both experiments. These simultaneous experiments afford a striking illustration of the effect of high concentrations on carbon dioxide exchange in comparison with medium concentrations of the order of 0.50 p.p.m.

The experiment with 0.50 p.p.m. had only a small effect on the photosynthesis of the plants on October 3. The second sulphur dioxide treatment with 0.44 p.p.m. had practically no effect on plant activity. On October 5 a somewhat greater effect was produced with 0.55 p.p.m., the carbon dioxide assimilation readings for several hours being definitely lower for the fumigated plot than for the control plot. On the other hand, the measurements on October 6 indicate very close agreement between the two plots.

The first 20 min. treatment with 1.75 p.p.m. of sulphur dioxide on Plot D-11 on October 3 caused respiration to predominate at a time when Plots C-14 and D-15 were showing high rates of photosynthesis. Similarly, the second 40 min. treatment on October 4 with 1.70 p.p.m. of sulphur dioxide produced an immediate inhibition of carbon dioxide assimilation, and throughout the day the carbon dioxide exchange was low. On October 5 the plants made a substantial

TABLE IV

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA

Intermittent treatments on three successive days at approximately 0.50 p.p.m.

Date 1935	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot D-15	Control plot C-14	Fumigated plot D-15	Control plot C-14
Oct. 2					19.48	22.55
3	10.20-10.40 a.m.	0.50	63.61	74.46	35.98	41.72
4	10.16-10.56 a.m.	0.44	37.38	42.41	31.10	37.62
5	10.40-11.40 a.m.	0.55	66.88	83.35	28.33	31.46
6			58.09	60.20	26.58	25.73
Total assimilation and respiration, Oct. 2 to 6 -----			225.96	260.42	141.47	159.08
Net assimilation, Oct. 2 to 6 -----			84.49	101.34		

recovery from the shock sustained under the influence of the gas, although the carbon dioxide assimilation was still greatly reduced. The night respiration during this period was somewhat higher than the control; these results confirm the data obtained in other experiments with high concentrations. Since no leaf injury was produced in either of these simultaneous experiments the effects described indicate that sulphur dioxide in sufficiently high concentrations is capable of exerting a profound inhibiting action on the chlorophyll mechanism without injury to either the chlorophyll or the protoplasm in the cells. The action is probably equivalent to the effect produced by a sudden reduction in light intensity.

TABLE V

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA

Intermittent treatments at 1.75 and 1.70 p.p.m.

Date 1935	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot D-11	Control plot C-14	Fumigated plot D-11	Control plot C-14
Oct. 3	10.30-10.50 a.m.	1.75	1.74	42.98	34.64	24.44
4	10.00-10.40 a.m.	1.70	10.16	42.41	37.00	37.62
5			20.14	83.35	41.82	31.46
6			20.61	60.20	28.93	25.73
Total assimilation and respiration, Oct. 3 to 6 -----			52.65	228.94	142.39	119.25
Net assimilation -----			-89.74	109.69		

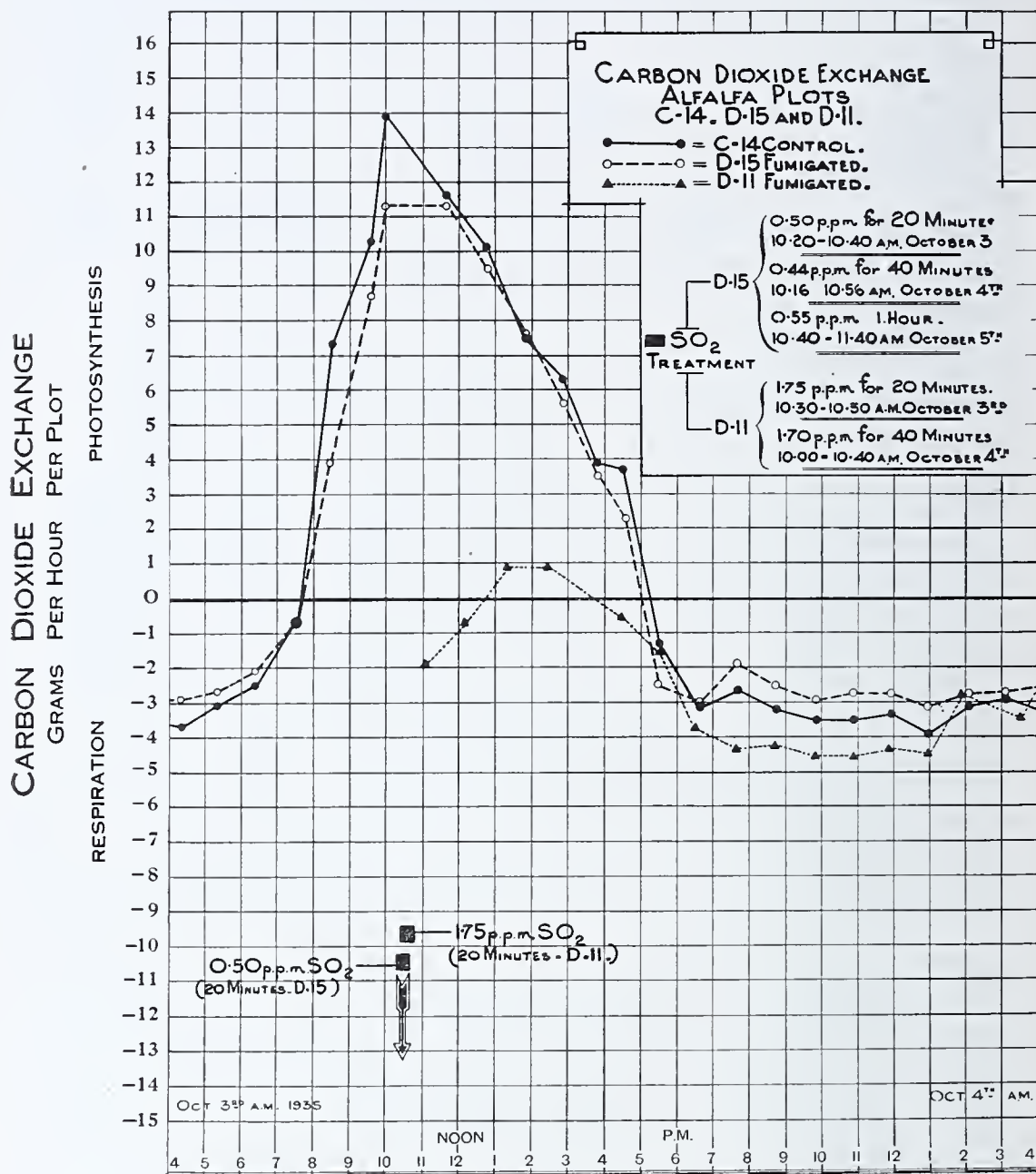


FIG. 4.

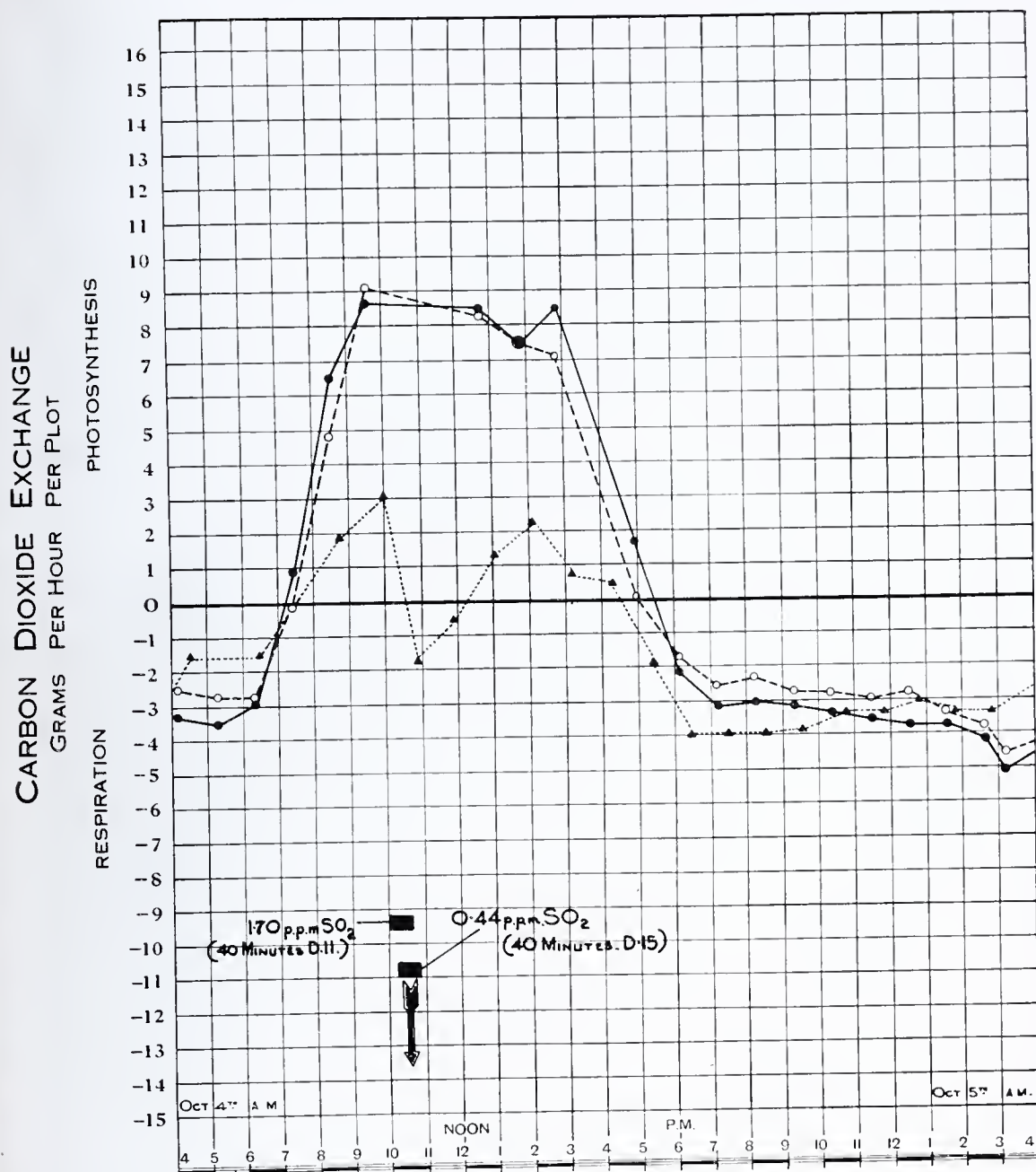


FIG. 5.

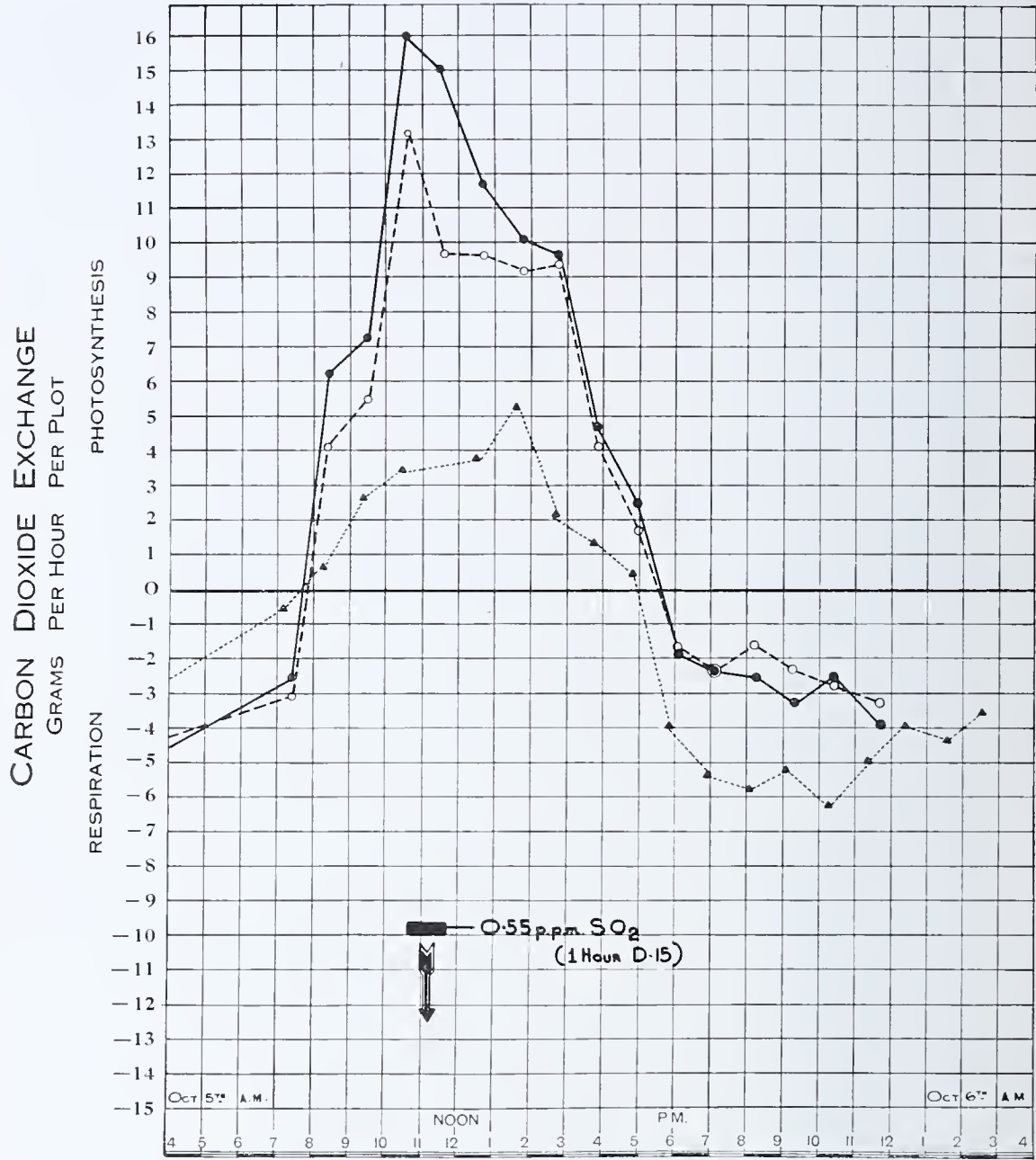


FIG. 6.

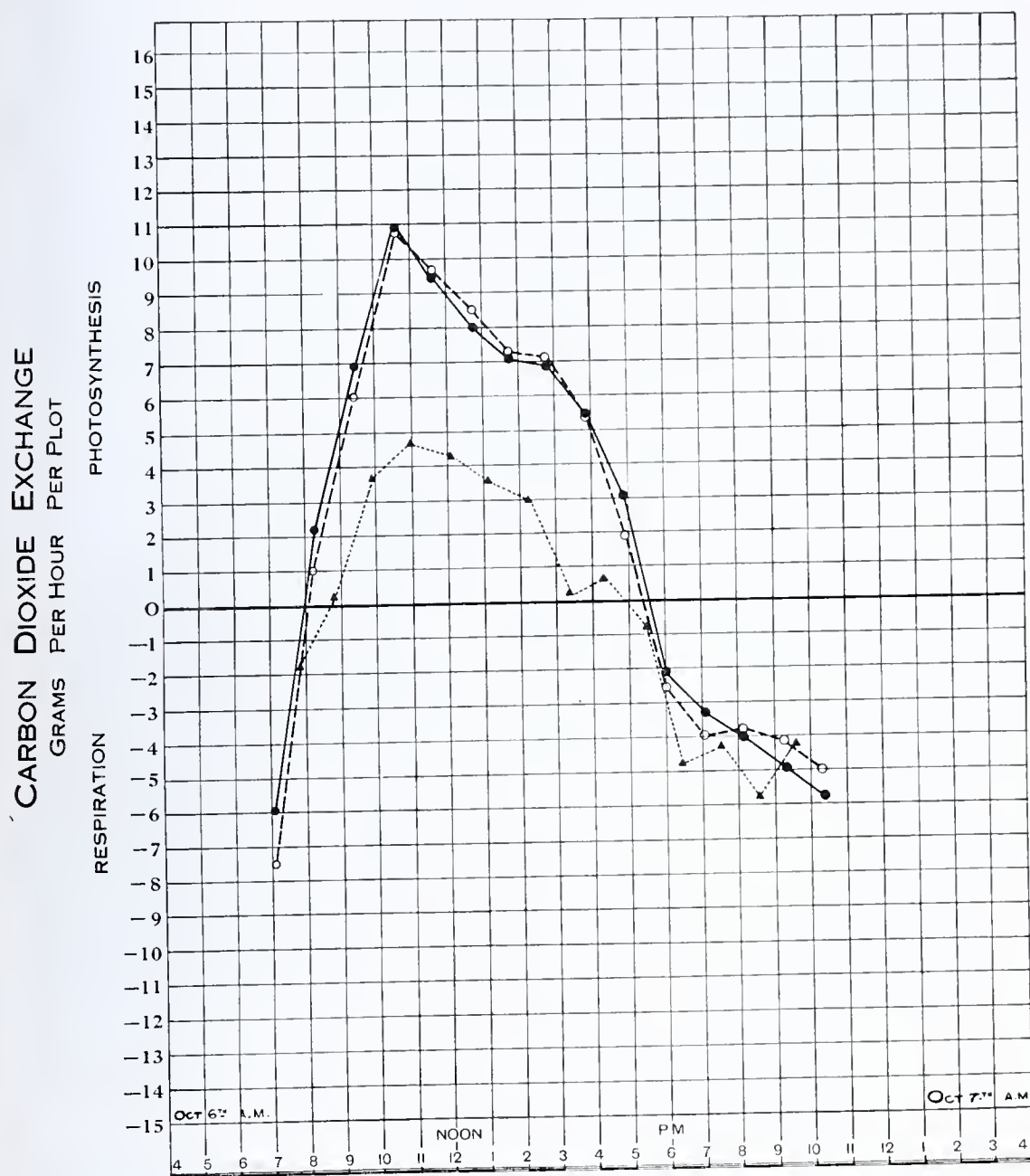


FIG. 7.

Treatment for One Hour during Darkness with Approximately 5.0 p.p.m.

The plants in Plot A-5 were fumigated from 8.40 to 9.40 p.m. on the night of September 14, 1935, the gas concentrations being 5.20 p.p.m. for the first 12 min., 4.64 for the next 32 min., and 4.50 p.p.m. for the remaining 16 min. Measurements of respiration and photosynthesis prior to the gas treatment indicated comparable rates for both Plot A-5 and its control A-4 (see Table VI).

During the period of the fumigation and for some hours afterwards the night respiration of the treated plants was lower than the controls, but from 2.00 a.m. to 7.00 a.m. the respiration rates on both plots were quite similar. Contrary to the effect of high concentrations of sulphur dioxide when present during the period of photosynthesis, this treatment did not produce any substantial reduction in the rate of assimilation, the observed decrease being probably due to the amount of injured leaves rather than to any inhibiting action (Table VI).

TABLE VI

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Treatment for one hour during darkness with 4.50 to 5.20 p.p.m.

Date 1935	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, min.	Av. conc., p.p.m.	Fumigated plot A-5	Control plot A-4	Fumigated plot A-5	Control plot A-4
Sept. 13			8.58	12.48	29.34	27.72
14	12	5.20)				
	32	4.64)	67.30	68.83	14.00	22.67
	16	4.50)				
15a			46.89	47.92	23.71	36.08
16b			23.36	25.04	15.34	14.19
17			92.92	102.72	42.43	36.78
18			46.23	66.18	26.67	21.41
Total assimilation and respiration, Sept., 13-18 -----			285.28	323.17	151.49	158.85
Net assimilation -----			133.79	164.32		

a. 38.8% of the leaves marked by sulphur dioxide—17.5% total injury.

b. Only a partial record of CO₂ exchange available for this day.

Two other experiments were carried out with high concentrations of sulphur dioxide on Plot I-3, the object being to compare the relative effect, in the absence of visible markings, of high concentrations of gas during night and morning. The plants were treated with 4.60 p.p.m. from 10.00 to 10.20 p.m., September 24, 1935. This was followed by a second treatment with 4.40 p.p.m. from 9.05 to 9.15 a.m., September 25.

The first gas treatment did not produce any markings on the leaves, but the second fumigation, although stopped at the first perceptible sign of visible leaf injury, nevertheless caused markings of a slight character to appear on about 10% of the leaves.

The night treatment had no marked effect on the rate of respiration of the plants. In the morning treatment, however, the photosynthesis of the fumigated plants was completely inhibited during the presence of the gas. There was very little recovery during the remainder of the day, the plants showing an abnormally low rate of assimilation. During the night of September 25-26 the rates of respiration of the fumigated and control plots were similar. On the morning of the 26th, when the plants in the control cabinet began to absorb carbon dioxide from the atmosphere, no absorption was noticeable in the fumigated plot. From 9.00 to 10.00 a.m. the rate of carbon dioxide assimilation of the fumigated plot was noticeably less than the control. Thereafter the treated plants recovered their ability to utilize carbon dioxide from the atmosphere to a considerable extent. Respiration values for the treated plot throughout the night of the 26th to 27th were normal, and on the morning of the 27th the rate of assimilation, although somewhat lower than that for the control plot, indicated a pronounced recovery from the effects of the fumigation.

Intermittent Treatments with Concentrations Varying from 0.27 to 2.46 p.p.m.

The effect of a series of short intermittent sulphur dioxide fumigations of 30 min. to one hour's duration with concentrations covering a wide range was investigated in order to demonstrate clearly the point at which sulphur dioxide exerts an inhibiting action on photosynthesis. It was hoped to carry this series of fumigations through without inflicting any injury on the plants, but appreciable markings appeared on the leaves after the sixth fumigation. As shown in Table VII, the fumigations were carried out during September 16-30. The plants were about 12 in. in height when the carbon dioxide measurements were begun. The records for the pre-fumigation period indicate almost identical respiration and photosynthesis values for the two plots. The sulphur dioxide treatments of September 16, 17, 18 and 19, with concentrations of 1.36, 2.00, 0.73, 0.82 and 0.71 p.p.m., resulted in definite reductions in the total amount of carbon dioxide assimilated during each of these days (Table VII). The fumigation of September 20 with 0.47 p.p.m. for 30 min. had no appreciable effect on the carbon dioxide assimilation. Similarly the fumigation of one hour's duration with 0.27 p.p.m. on September 21 had no effect on carbon dioxide exchange. The fumigations of September 22, 25 and 30 with concentrations of 2.46, 0.57 and 0.52 p.p.m. again caused a reduction in the amount of carbon dioxide assimilated. During the intervening periods when there was no sulphur dioxide present a substantial recovery in assimilation took place.

At the end of this experiment sulphur dioxide markings were present on 18% of the leaves. In comparison with the control, the net amount of carbon dioxide absorbed was reduced about 17%.

TABLE VII
EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Intermittent treatments for 7.5 hr. at 0.27 to 2.46 p.p.m.

Date 1936	Sulphur dioxide treatment			Carbon dioxide assimilated daily, gm.		Carbon dioxide respired nightly, gm.	
	Time	Duration, min.	Average conc., p.p.m.	Fumigated plot G-7	Control plot H-8	Fumigated plot G-7	Control plot H-8
Sept. 14	10.15—10.45 a.m.	30	1.36)	2.50	2.50	11.00	10.70
15	3.00—3.30 p.m.	30	2.00)	52.25	51.45	7.10	8.70
16	1.40—2.10 p.m.	30	0.73	16.55	23.05	18.00	17.70
17	10.05—10.35 a.m.	30	0.82	39.85	44.00	16.30	18.60
18	10.25—10.55 a.m.	30	0.71	50.85	55.00	28.65	29.70
19	9.45—10.15 a.m.	30	0.47	62.20	69.95	23.15	27.05
20	11.00—12.00 noon	60	0.27	49.00	50.75	23.30	25.20
21	9.35—10.35 a.m.	60	0.31)	29.40	29.60	48.70	45.50
22	3.40—4.10 p.m.	30	2.46)	30.80	37.15	42.80	30.55
23				60.85	64.90	51.10	53.40
24				20.10	28.50	27.75	29.55
25	9.35—10.35 a.m.	60	0.57	54.70	72.70	21.70	24.50
26				82.92	86.87	27.10	29.80
27				72.20	76.95	47.10	48.30
28				60.60	66.30	35.40	42.20
29				50.70	53.10	37.05	40.30
30	10.00—10.30 a.m.	30	0.52	59.17	68.17	24.67	27.37
Oct. 1 ^a				57.90	62.15	—	—
Total assimilation and respiration, Sept. 14 to Oct. 1				852.54	943.09	490.87	509.12
Net assimilation, Sept. 14 to Oct. 1				361.67	433.97		

^a Sulphur dioxide markings found on 18% of the leaves—only 5% of foliage severely injured.

Intermittent Treatments with Concentrations Varying from 0.12 to 0.75 p.p.m.

During the period August 1 to 12, 1936, the plants in Plot G-3 were subjected to a series of sulphur dioxide treatments with average concentrations of 0.18 to 0.56 p.p.m., the total duration of gas being 98.67 hr. The average height of the alfalfa plants was about 12 in. at the start of the experiment. The plants had been treated with sulphur dioxide gas for 57.5 hr. continuously with average concentrations of 0.24 to 0.31 p.p.m. before the carbon dioxide measurements were begun on August 5 (see Table VIII). The total apparent assimilation and night respiration at this time was slightly lower for the treated plants. On August 6-7 the plot was fumigated for 26.5 hr. with an average concentration of 0.18 p.p.m. During this period the photosynthesis of the treated plants was actually higher than the control. A further fumigation carried out on August 8 for four hours with 0.24 p.p.m. apparently reduced the rate of photosynthesis. Symptoms of injury were evident on the leaves at this time. The following day, August 9, the plants were again fumigated with 0.56 p.p.m. for 6.67 hr., from 4.00 p.m. to 10.40 p.m. Owing to the fact that this fumigation was carried out in partial darkness the effect on photosynthesis was slight, compared with the reduction in respiration. On August 10 sulphur dioxide markings of the marginal type were present on about 10% of the leaves, the symptoms being confined to the top leaves of the plants. The last treatment was carried out on the morning of August 11 with a concentration of 0.26 p.p.m. for four hours. The respiration and photosynthesis were reduced considerably on August 11-12, but it is apparent that at least a part of this decrease was due to the presence of injured leaves.

The data in Table VIII indicate that the net assimilation values for the two plots from August 5 to 12 agree within about 1%. For the period August 5-10, *i.e.*, the time prior to the appearance of a substantial number of injured leaves, the net assimilation of the treated plot is about 6% greater than that of the control.

Another series of intermittent fumigations with average concentrations of 0.22 to 0.60 p.p.m. was carried out in September, 1936. The sulphur dioxide treatments of Plot G-16 (Control H-17) are shown in Table IX. Slight symptoms of chlorosis were noted on September 4 and 11. The extent of the markings was not appreciable.

The first seven fumigations were carried out in daylight at a time when photosynthesis was in evidence, while the last fumigation was carried out during the period of respiration.

The carbon dioxide exchange data cover continuous measurements from September 1 to September 14. The preliminary readings taken on September 1 prior to the gas treatment show a similar state of plant activity in both plots. The successive gas treatments caused a definite reduction in the amount of

TABLE VIII

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Intermittent treatments for 98.67 hr. with concentrations of 0.18 to 0.56 p.p.m.

Date 1936	Sulphur dioxide treatment		Total apparent assimilation CO ₂ , gm.		Night respiration CO ₂ , gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot G-3	Control plot H-3	Fumigated plot G-3	Control plot H-3
Aug. 1a	16.5	0.238				
2	24.0	0.268				
3b	17.0	0.310				
4						
5			27.92	31.35	18.58	20.57
6c	15.0)	0.180	36.04	28.63	9.10	14.51
7	11.5)	0.180	58.68	55.25	25.86	21.84
8d	4.0	0.238	41.79	47.41	14.07	19.10
9e	6.67	0.560	35.02	38.40	6.95	14.83
10*			37.45	41.06	27.30	24.34
11	4.0	0.260	44.36	63.02	23.35	31.20
12			35.71	46.74	18.63	30.15
Total			316.97	351.86	143.84	176.54
Net assimilation, Aug. 5-12			173.13	175.32		
Total, Aug. 5-10			236.90	242.10	101.86	115.19
Net assimilation, Aug. 5-10			135.04	126.91		

a. Sulphur dioxide treatment begun 7.30 a.m.

b Sulphur dioxide treatment stopped at 5.00 p.m., Aug. 3. A maximum concentration of 0.88 p.p.m. was attained. Very slight markings on 3.3% of plants.

c Sulphur dioxide treatment from 9.00 a.m., August 6, to 11.30 a.m., August 7.

d Sulphur dioxide treatment from 9.40 a.m. to 1.40 p.m., August 8.

e Sulphur dioxide treatment from 4.00 p.m. to 10.40 p.m., August 9.

* Sulphur dioxide markings of the marginal type were present on 10% of the leaves.

carbon dioxide assimilated by the plants. The treatments which proved most effective in reducing photosynthesis were those carried out during the morning. The last fumigation on September 12, from 5.40 p.m. to 10.25 p.m. had no effect whatever on the respiration or on the photosynthesis the following day. A complete recovery in assimilation is evident on the last three days of this experiment. The net assimilation of the treated plot is 89.8% of that of the control.

A series of nine intermittent sulphur dioxide fumigations was carried out on Plot F-2 during June 25 to July 10. The plants on June 25 were about 14 days old since the date of the last cutting and in the primary leaf stage. The average concentrations in these treatments varied from 0.12 to 0.61 p.p.m. while the

TABLE IX

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Intermittent treatments for 29.25 hr. at 0.22 to 0.60 p.p.m.

Date 1936	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot G-16	Control plot H-17	Fumigated plot G-16	Control plot H-17
Aug. 31					3.80	4.70
Sept. 1			80.65	80.85	26.30	29.50
2	11.0	0.22	20.25	25.35	33.10	33.90
3	4.0	0.25	57.90	67.10	53.50	54.50
4	1.5	0.60	31.45	43.55	51.20	44.10
5			55.15	58.45	32.30	38.50
6			34.50	35.95	24.20	27.80
7	2.0	0.43	24.75	30.60	26.10	31.20
8			50.95	56.70	6.00	15.90
9	2.0	0.48	57.15	58.90	13.20	16.90
10	2.0	0.45	26.40	31.80	25.80	19.80
11	2.0	0.50	24.15	31.90	18.10	17.37
12	4.75	0.48	70.75	69.75	18.10	18.10
13			78.45	79.40	1.70	1.70
14			52.30	52.75	---	---
Total assimilation and respiration, Aug. 31-Sept. 14 -----			664.80	723.05	333.40	353.97
Net assimilation, Aug. 31-Sept. 14 ----			331.40	369.08		

variation in the maximum concentrations was from 0.30 to 1.08 p.p.m. The total duration of the sulphur dioxide fumigations was 80.25 hr. The sulphur dioxide and carbon dioxide data are given in Table X.

With regard to the effect of these sulphur dioxide treatments on carbon dioxide exchange, the day fumigations caused a reduction in the apparent assimilation whenever the average concentration was in excess of 0.38 p.p.m. On the other hand, the fumigations carried out in darkness had no appreciable effect. The net amount of carbon dioxide assimilated by the treated plants throughout the period of this test was 84.5% of the controls. Some of this decrease must be ascribed to the reduction in active leaf surface which necessarily ensued as a result of visible markings on about 30% of the leaves.

Plot F-2 and its control, E-1, were cut on July 11 and carbon dioxide measurements resumed on July 21 when the plants were 10 days old. The total apparent assimilation each day, from July 21 to August 4, 1936, and the sulphur dioxide treatments are given in Table XI. During this period the night respiration was not measured owing to interruptions in power supply.

Prior to the first fumigation the total apparent assimilation for plot F-2 was 54.05 gm. and for the control, E-1, 53.6 gm. During the period of July 24-26,

which includes the first fumigation with 0.16 p.p.m. of sulphur dioxide, the treated plants absorbed carbon dioxide in greater quantity than the controls, the increase being about 6.5%. From July 27-29 during the second long treatment with 0.41 p.p.m., there ensued a reduction of 27% in the amount of carbon dioxide assimilated. This second fumigation was quite severe, markings being in evidence on July 28 on about 50% of the plants, but only 12% of the leaves could be regarded as totally injured. From July 30 to August 2 a substantial

TABLE X

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Intermittent treatments for 80.25 hr. at 0.12 to 0.61 p.p.m.

Date 1936	SO ₂ treatment		Max. conc., p.p.m.	CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.		Fumigated plot F-2	Control plot E-1	Fumigated plot F-2	Control plot E-1
June 25				41.40	45.60	20.9	26.2
26)	20.0	0.28	0.74	70.10	69.20	28.1	16.6
27)				81.25	92.50	1.1	1.0
28				104.77	114.37	—	—
29	7.0	0.41	0.62	60.25	72.70	17.0	13.6
30)	14.0	0.12	0.30	74.55	83.15	30.4	24.4
July 1)	6.0	0.24		51.00	54.30	—	—
2)	3.0	0.33		48.25	47.45	26.5	21.9
3)	3.25	0.60	0.66	75.35	83.40	18.0	19.9
4	4.1	0.61	1.08	27.10	43.00	11.5	14.8
5				35.70	40.00	7.0	5.2
6	7.3	0.38	0.52	53.55	52.85	14.2	13.5
7	8.0	0.48	0.60	20.30	23.60	20.2	20.0
8	6.6	0.60	0.68	45.00	76.80	9.8	10.7
9				42.45	44.80	7.3	10.9
10				87.40	92.55	3.7	5.2
Total assimilation and respiration, June 25 to July 10 -----				918.42	1036.32	215.70	203.90
Net assimilation, June 25 to July 10 -----				702.72	832.42		

Sulphur Dioxide Treatments

June 26, 3.30 p.m., to June 27, 11.30 a.m. Slight markings on some leaves.

June 29, 9.20 a.m., to 4.20 p.m.

June 30, 4.30 p.m., to July 1, 1.20 p.m.

July 2, 5.00 p.m., to 8.00 p.m.

July 3, 1.30 p.m., to 4.45 p.m.

July 4, 9.45 a.m., to 1.55 p.m. Markings on 5% of leaves.

July 6, 9.20 a.m., to 4.40 p.m.

July 7, 8.45 a.m., to 4.45 p.m.

July 8, 8.40 a.m., to 3.20 p.m.

July 9, Sulphur dioxide markings present on 30.4% of the leaves. 2.5% of leaves estimated as totally injured.

TABLE XI

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Intermittent treatments for 47.0 hr. with concentrations of 0.160 to 0.753 p.p.m.

Date 1936	Sulphur dioxide treatment		Total apparent assimilation CO ₂ , gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot F-2	Control plot E-1
July 21			21.0	19.2
22			19.6	19.4
23			13.9	15.0
24	8.0) a	0.160	32.0	30.9
25	14.0)		24.3	21.7
26			63.8	60.2
27	13.75) b	0.410	21.3	26.9
28*	8.25)		15.5	22.8
29			19.3	27.2
30			42.0	41.8
31			13.8	15.9
Aug. 1			25.7	24.1
2			33.1	34.2
3	1.5 c	0.753	10.4	27.0
4	1.5 d	0.330	24.8	28.7
Total			380.5	415.0
Total apparent assimilation, July 21-23 incl.			54.5	53.6
Total apparent assimilation, July 24-26 incl.			120.1	112.8
Total apparent assimilation, July 27-29 incl.			56.1	76.9
Total apparent assimilation, July 30-Aug. 2 incl.			114.6	116.0
Total apparent assimilation, Aug. 3-4 incl.			35.2	55.7

a. Plants treated with sulphur dioxide from 4.00 p.m., July 24, to 2.00 p.m., July 25, at average concentration of 0.160 p.p.m., maximum 0.31 p.p.m.

b. Sulphur dioxide treatment began 10.15 a.m., July 27, and stopped at 8.15 a.m., July 28.

c. Sulphur dioxide treatment from 9.10 a.m. to 10.40 a.m., August 3.

d. Sulphur dioxide treatment from 8.40 a.m. to 10.10 a.m., August 4.

* This fumigation injured 12% of the leaves.

recovery took place, the carbon dioxide absorption readings for the fumigated and the control plots being similar. Additional markings were produced by the sulphur dioxide treatment of August 3, and the data covering this day show a substantial reduction in the carbon dioxide assimilation.

Intermittent Treatments with Average Concentrations of 0.31 to 0.38 p.p.m.

A series of experiments was carried out with concentrations in the range of 0.30 to 0.40 p.p.m., the maximum not exceeding 0.43 p.p.m., (see Table XII). The plants in Plot E-13 were fumigated daily from August 24 to August 28, 1936, and after a rest period on the 29th, were again treated on August 30. Of these six treatments, four were carried out in full sunlight and two under conditions of low average light intensity, the gas being present part of the time at

night. A few slight marginal and intercostal markings were noted on August 28 and 29, but the extent of these markings was too small to be estimated. There was no further development of symptoms of sulphur dioxide injury at the conclusion of the experiment.

No appreciable effect on photosynthesis or night respiration is evident at these sulphur dioxide concentrations. The total apparent assimilation of the fumigated plot is 100.5% of that of the control, and the total night respiration 104.0%. A considerable increase in respiration occurred during the night fumigation of August 27, when the average concentration was 0.38 p.p.m. for 11 hr. and concentrations slightly over 0.40 p.p.m. were present for 2.5 hr. The net amounts of carbon dioxide assimilated by the fumigated and the control plots agree within 2%.

TABLE XII
EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Intermittent treatments for 25.4 hr. at 0.31 to 0.38 p.p.m.

Date 1936	Sulphur dioxide treatment			CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Max. conc., p.p.m.	Fumigated plot E-13	Control plot F-14	Fumigated plot E-13	Control plot F-14
Aug. 22				17.85	15.20	1.50	2.60
23				36.05	35.30	16.50	14.90
24	2.0 a	0.32	0.37	43.75	44.45	18.20	15.50
25	2.0 b	0.34	0.36	65.00	67.25	12.00	14.30
26	2.1 c	0.31	0.39	44.90	51.70	35.30	34.25
27	11.0 d	0.38	0.43	53.40	46.20	32.10	20.50
28	6.3 e	0.36	0.38	41.60	35.60	30.40	30.40
29				36.45	35.75	18.70	23.90
30	2.0 f	0.33	0.35	43.00	50.90	19.10	20.10
31				52.30	49.50	—	—
Total assimilation and respiration, Aug. 22 to Aug. 31				434.30	431.85	183.80	176.45
Net assimilation, Aug. 22 to Aug. 31				250.50	255.40		

a. Sulphur dioxide treatment from 9.45 a.m. to 11.45 a.m.

b. Sulphur dioxide treatment from 9.30 a.m. to 11.30 a.m.

c. Sulphur dioxide treatment from 10.40 a.m. to 12.50 p.m.

d. Sulphur dioxide treatment from 9.15 p.m., Aug. 27, to 8.00 a.m., August 28.

e. Sulphur dioxide treatment from 4.00 p.m. to 10.20 p.m., August 28.

f. Sulphur dioxide treatment from 9.15 a.m. to 11.15 a.m.

Intermittent Treatments with Concentrations of 0.21 to 0.70 p.p.m. for 32.8 Hours

A series of daily fumigations was carried out on Plot C-14 from July 27 to August 6, 1937. Carbon dioxide measurements were begun on July 24 at a time when the plants were about 10 in. in height. A summary of the sulphur

dioxide treatments and the results on photosynthesis and night respiration are given in Table XIII. All the sulphur dioxide treatments were carried out in daylight, the fumigations being generally begun between 9.00 and 10.00 a.m.

Prior to the gas treatment, Plot C-14 showed a consistent increase in carbon dioxide absorption over its control, D-15. This situation was reversed on July 29, after the third sulphur dioxide treatment. The difference between the two plots became more marked on August 5 after a fumigation with 0.57 p.p.m. of sulphur dioxide for one hour. The visible effects of these fumigations consisted of acute markings on 11.8%, and chlorotic markings on 4%, of the leaves. These markings were caused mainly by the last two fumigations.

As shown in Table XIII the total assimilation from July 24 to August 4 is the same for both plots but the night respiration for C-14 is slightly greater. For the period July 24 to August 9 the net assimilation for Plot C-14 is about 95% of that of the control.

TABLE XIII

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA

Intermittent treatments for 32.8 hr. at 0.21 to 0.70 p.p.m.

Date 1937	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot C-14	Control plot D-15	Fumigated plot C-14	Control plot D-15
July 24			27.8	20.7	19.7	19.3
25			25.8	18.1	18.5	23.3
26			25.1	14.4	20.6	19.5
27	4.0	0.24	42.3	34.1	33.7	31.3
28	2.0	0.21	37.3	33.7	27.2	21.0
29	4.0	0.28	33.7	39.6	9.6	9.6
30	5.0	0.28	84.8	97.2	12.8	11.2
31	4.0	0.32	107.4	107.6	6.0	6.0
Aug. 1			61.3	65.6	7.0	7.4
2	4.3	0.29	129.9	134.7	9.6	10.5
3	4.0	0.31	61.4	69.0	29.7	28.7
4	3.0	0.34	36.2	38.4	30.2	32.2
5	1.0	0.57	55.8	73.7	22.9	27.4
6	1.5	0.70	81.6	96.1	10.4	14.8
7			77.5	85.6	18.1	19.7
8			71.1	79.5	7.9	10.5
9			40.0	37.5	3.0	2.8
Total assimilation and respiration, July 24 to Aug. 9 -----			999.0	1045.5	286.9	295.2
Net assimilation, July 24 to Aug. 9 ..			712.1	750.3		
Total assimilation and respiration, July 24 to Aug. 4 -----			673.0	673.1	228.6	220.0
Net assimilation, July 24 to Aug. 4...			444.4	453.1		

Treatment with 0.124 p.p.m. for 415 Hours

A long experiment was carried out during the growing season of 1937, from June 26 to July 21, with average concentrations of 0.10 to 0.18 p.p.m., the alfalfa being fumigated for relatively long periods of time with only short rest periods between fumigations (see Table XIV). The plants were about 12 to 14 in. in height at the start of this experiment. Some marginal sulphur dioxide markings were present on July 3, after about 140 hr. of fumigation. Additional chlorotic

TABLE XIV
EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Intermittent treatment for 415 hr. at 0.124 p.p.m.

Date 1937	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot A-11	Control plot B-12	Fumigated plot A-11	Control plot B-12
June 26	21 b	0.18	10.98	9.75	19.99	19.34
27			18.16	17.25	32.42	28.80
28			19.84	19.39	17.65	15.52
29			51.91	49.70	6.91*	6.98*
30			78.04	72.86	5.59*	3.21*
July 1	161 c	0.10	96.50	89.13	12.17	12.17
2			55.41	59.36	26.00	23.69
3 a			62.80	64.32	15.00	15.23
4			68.21	76.24	18.50	18.70
5			71.97	79.61	11.44	10.59
6	144 d	0.12	118.41	117.08	14.21	14.00
7			77.46	82.49	17.26	15.05
8			52.53	58.49	40.70	41.99
9			77.18	76.48	19.18	19.13
10			84.05	99.76	18.91	17.35
11			44.53	51.74	18.07	16.97
12			73.94	81.82	18.95	18.24
13			132.10	140.33	15.10	14.10
14			120.41	124.14	8.52	9.76
15			106.22	108.17	14.10	10.70
16	89 e	0.15	110.97	114.16	18.20	17.37
17			87.10	93.54	29.80	16.80
18			62.17	66.31	10.77	1.84
19			79.01	92.84	21.20	12.92
20			48.40	56.00	24.10	23.10
21			28.30	45.20	36.00	22.70
Total assimilation and respiration, June 26 to July 21 -----			1836.60	1946.16	490.74	426.25
Net assimilation, June 26 to July 21----			1345.86	1519.91		

a. Light marginal injury on plot.
 * Respiration data for this day incomplete.
 b. Sulphur dioxide treatment 3.20 p.m., June 26—12.20 p.m., June 27.
 c. Sulphur dioxide treatment 4.20 p.m., June 28—9.20 a.m., July 5.
 d. Sulphur dioxide treatment 2.30 p.m., July 6—2.30 p.m., July 12.
 e. Sulphur dioxide treatment 4.00 p.m., July 15—9.00 a.m., July 19.

symptoms appeared after 250 hr. of fumigation. Throughout this experiment the humidity was extremely high, generally between 70 and 90%. Such conditions favor an extremely high rate of absorption of sulphur dioxide gas, and it is not surprising, therefore, that symptoms of injury were found on the leaves after July 3, even at these comparatively low concentrations.

An increase in assimilation is evident during the first six days of gas treatment. On the 7th day, coincident with the appearance of marginal markings on the leaves, the photosynthesis of the treated plot is definitely lower than that of the control. Thereafter on most days the daily total assimilation of carbon dioxide is reduced and the night respiration increased. For the whole period of the experiment the total assimilation of the treated plot is 5.6% less than that of the control and the respiration about 15% greater.

Treatment with 0.41 p.p.m. for 17.25 Hours

Plot I-15 was treated with 0.41 p.p.m. sulphur dioxide for 17.25 hr., from 2.10 p.m., August 1, to 7.30 a.m., August 2, 1935. The plants were, therefore, fumigated for the greater part of the time during the period of night respiration. The data on carbon dioxide exchange covering the period from 2.50 a.m., August 1, to 6.30 a.m., August 7, are given in Table XV.

The total assimilation of the treated plot for this period is 101.5, expressed as a percentage of the control. The night respiration is 10.5% less than that of

TABLE XV

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA

Continuous treatment for 17.25 hr. at 0.41 p.p.m.

Date 1935	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot 1-15	Control plot 1-14	Fumigated plot 1-15	Control plot 1-14
Aug. 1) a	17.25	0.41	31.15	31.12	10.74	10.28
2)			20.06	21.50	37.28	39.20
3			55.68	52.70	17.24	22.30
4			67.30	70.94	18.00	18.08
5			66.40	61.00	30.46	34.90
6			105.12	102.98	21.92	25.20
7					8.28	10.96
Total assimilation and respiration, Aug. 1 to 7 -----			345.71	340.24	143.92	160.92
Net assimilation, Aug. 1 to 7 -----			201.79	179.32		

a. Plot I-15 treated with sulphur dioxide from 2.10 p.m., August 1, to 7.30 a.m., August 2.

the control, while the net assimilation is about 12% greater. Only a negligible number of leaves was marked by sulphur dioxide, as a result of this treatment.

Treatment with 0.35 p.p.m. for 48 Hours

This experiment was carried out from 12 noon, July 20, to 12 noon, July 22, 1935, on Plot E-18, the control plot being the adjoining Plot E-17. The fumigation caused slight marginal injury on a few plants only, no leaves being found with intercostal markings. Sulphur dioxide symptoms were too few in themselves to measurably affect the rate of carbon dioxide exchange, as shown in Table XVI.

During the first day of the gas treatment there was no interference with either the photosynthesis or the night respiration. Carbon dioxide data are not available for July 21, the recorders not being operated during this day, but on the 22nd the measurements indicated an appreciable decrease in photosynthesis and increase in night respiration had taken place in the fumigated plot. However, on July 23, and subsequently, the apparent carbon dioxide assimilation of the fumigated plot was maintained at a comparable rate to that of the control plot, thus indicating that the treated plants recovered their normal ability to assimilate carbon dioxide after the removal of the sulphur dioxide gas. The net assimilation of the fumigated plot from July 20-25, was 80.7% of that of the control.

TABLE XVI

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA

Continuous treatment for 48 hr. at 0.35 p.p.m.

Date 1935	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot E-18	Control plot E-17	Fumigated plot E-18	Control plot E-17
July 20) a	48	0.35	36.76	36.76	16.69	17.02
22)			31.53	46.62	25.82	17.87
23			38.36	37.42	18.72	13.96
24			32.42	33.84	1.14	—
25			48.93	49.66	7.24	8.80
Total assimilation and respiration, July 20 to 25 -----			188.00	204.30	69.61	57.65
Net assimilation, July 20 to 25 -----			118.39	146.65		

a. Plot E-18 treated with sulphur dioxide from 12 noon, July 20, to 12 noon, July 22. Only a few leaves marked.

The Effect of Sulphur Dioxide Fumigations of the Continuous Type on Carbon Dioxide Exchange

Continuous Treatment with an Average Concentration of 0.373 p.p.m. for 378 Hours

A long experiment was carried out at an average sulphur dioxide concentration of 0.373 p.p.m., the daily average gas concentrations and the apparent assimilation and night respiration being shown in Table XVII. A decrease in the rate of carbon dioxide assimilation became evident during the third day of continuous fumigation, the total apparent assimilation for this day being 69.92 gm. for the fumigated plot, compared with 92.29 gm. for the control. Thereafter, throughout the duration of the gas treatment the rates of photosynthesis and night respiration, except for October 14 and 15, were reduced. However, on October 25, from 10.00 a.m. onwards, after the gas treatment was discontinued, the treated plants recovered their normal rates of photosynthesis and respiration.

TABLE XVII

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Continuous treatment for 378 hr. with an average concentration of 0.373 p.p.m.

Date 1935	Sulphur dioxide treatment		Total apparent assimilation CO ₂ , gm.		Night respiration CO ₂ , gm.	
	Duration, hr.	Av. conc., p.p.m.	Fumigated plot C-17	Control plot D-16	Fumigated plot C-17	Control plot D-16
Oct. 7	10	0.634 a				
8	24	0.456	40.06	39.86	32.24	44.55
9	24	0.252	69.92	92.29	10.00	20.85
10	24	0.353	54.17	69.03	5.83	19.73
11	24	0.377	44.39	54.59	41.81	46.56
12	24	0.301	48.45	65.64	7.50	9.99
13	24	0.293	58.65	81.28	7.38	23.44
14	9	0.100	9.02	17.06	56.31	40.75
15	No treatment		34.78	41.90	44.84	38.24
16	13	0.435	44.16	62.64	31.86	48.54
17	24	0.470	36.64	59.74	13.72	65.50
18	24	0.484	47.92	65.94	12.88	39.92
19	24	0.436	22.52	24.62	21.56	51.48
20	24	0.326	50.58	97.44	33.88	61.78
21	24	0.274	30.18	74.20	49.54	90.16
22	24	0.336	12.53	58.22	38.23	89.25
23	24	0.391	21.94	59.79	68.92	138.03
24	24	0.446	40.46	79.87	58.74	103.36
25	10	0.345	60.64	62.35	39.79	38.85
26b	No treatment		36.02	27.77	5.60	1.44
Total -----			763.03	1134.23	580.63	972.42
Net assimilation -----			182.40	161.81		

a. Plot C-17 treated with sulphur dioxide continuously from 2.00 p.m., October 7, to 9.00 a.m. October 14, and from 11.00 a.m., October 16, to 10.00 a.m., October 25.

b. Measurements of carbon dioxide exchange discontinued at 11.16 a.m., October 26.

The observed decrease in photosynthesis on October 9 coincided with the appearance of sulphur dioxide lesions on the leaves. This was confined to the leaves on the upper portions of the plants and consisted of spotted, intercostal markings. As the experiment progressed, a considerable number of leaves assumed a noticeably chlorotic appearance. At the conclusion of the experiment 8% of the leaves were found to be totally injured and 17% contained markings of a chlorotic type.

The general effect of this long fumigation with high average concentrations was a diminution of plant activity, correlated with a noticeable decrease in transpiration. Owing to the marked decrease in night respiration of the fumigated plants the net amount of carbon dioxide assimilated was 11.3% greater for the fumigated than for the control plot.

As this experiment was carried out in the autumn when the top growth of alfalfa was diminishing, the night respiration from October 16 onwards is considerably greater than in September or earlier in the growing season.

Continuous Treatment with Average Concentrations of 0.05 to 0.21 p.p.m. for 504 Hours

In this experiment the alfalfa plants were subjected to continuous fumigation with low concentrations of sulphur dioxide practically throughout the growth of a crop. The records of carbon dioxide exchange and sulphur dioxide concentrations for the period August 13 to September 4, 1935, are summarized in Table XVIII. The temperature, humidity and light intensity were recorded continuously throughout the period of the test, no appreciable differences being noted in this respect between the control and fumigation cabinets. The treatment was carried out under conditions of comparatively high humidity and high rate of gas absorption.

Throughout the treatment no acute symptoms of sulphur dioxide injury were observed and the number of chlorotic and senescent leaves towards the end of the experiment was not any greater in the fumigated than in the control plot.

The carbon dioxide data show that the total apparent assimilation of the fumigated plot was about 4.5% less and the total night respiration about 9.5% less than that of the control. The net assimilation, on the other hand, for the period of the experiment was 101.5% of that of the control.

Continuous Treatment with Average Concentrations Varying from 0.08 to 0.64 p.p.m.

The concentrations in this experiment were varied in such a manner as to cover the range from about 0.10 to 0.75 p.p.m. The experiment was begun on June 7 and continued to June 22, the plants in Plot B-1 being treated with sulphur dioxide, from June 10 to 20 for a total duration of 222.8 hr. The data

TABLE XVIII

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Continuous treatment for 504 hr.

Date 1935	SO ₂ treatment		CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Av. conc., p.p.m.	Max. conc., p.p.m.	Fumigated plot C-11	Control plot C-12	Fumigated plot C-11	Control plot C-12
Aug. 13			31.9	29.1	15.5	20.7
14	0.107	0.19	61.7	65.9	17.8	11.4
15	0.151	0.20	66.2	72.9	33.4	42.1
16	0.081	0.14	62.3	63.3	31.7	34.8
17	0.074	0.15	47.2	47.9	14.1	20.3
18	0.065	0.07	66.9	64.3	9.1	8.4
19	0.088	0.11	68.0	72.0	—	—
20	0.084	0.12	63.5	63.3	11.6	8.6
21	0.072	0.12	75.5	75.1	6.8	12.5
22	0.051	0.08	68.6	72.6	8.2	10.0
23	0.056	0.08	32.4	37.4	31.9	29.4
24	0.082	0.16	28.1	38.2	46.4	40.8
25	0.075	0.10	10.4	14.8	30.4	31.6
26	0.067	0.10	29.8	31.6	32.7	32.5
27	0.118	0.21	24.2	23.6	20.8	29.4
28	0.074	0.19	20.3	19.4	36.3	42.6
29	0.046	0.11	56.9	62.6	20.0	20.1
30	0.052	0.14	27.3	23.4	35.6	40.6
31	0.098	0.12	48.1	51.9	32.7	35.3
Sept. 1	0.213	0.44	49.9	56.0	22.6	33.3
2	0.154	0.44	46.5	41.5	25.9	35.7
3	0.099	0.17	52.1	58.2	32.4	33.1
4	0.063	0.09	49.5	52.0	29.1	29.1
Total assimilation and respiration, Aug. 13-Sept. 4 -----			1087.3	1137.0	545.0	602.3
Net assimilation, Aug. 13-Sept. 4-----			542.3	534.7		

covering the sulphur dioxide treatment and the carbon dioxide exchange are summarized in Table XIX.

For three days prior to the gas treatment the total apparent assimilation for Plot B-1 was 145.8 gm., and for the control plot, A-2, 152.7 gm., the ratio of B-1 to A-2 being 95.5%. During the same period the night respiration for B-1 amounted to 62.2 gm. and for A-2, 52.5 gm. It is evident, therefore, that prior to the gas treatment the plants in B-1 were assimilating carbon dioxide at a somewhat smaller rate and respiring at a greater rate than the control plants. For approximately 120 hr. of the sulphur dioxide treatment, until June 15, during which period the plants in B-1 were treated with comparatively low concentrations of gas, this trend was reversed. The total apparent assimilation for B-1 on June 10, 11, 12, 13 and 14 was greater than that for the control, whereas the night respiration over this period was slightly lower than that for the control, so that there was a definite increase in the net quantity of carbon dioxide

TABLE XIX
EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA
Continuous treatment with sulphur dioxide for 222.8 hr.

Date 1936	Sulphur dioxide treatment			Total apparent assimilation CO ₂ , gm.		Night respiration CO ₂ , gm.	
	Avg. conc., p.p.m.	Max. conc., p.p.m.	Duration of max. conc., hr.	Fumigated plot B-1	Control plot A-2	Fumigated plot B-1	Control plot A-2
June 7				26.9	31.6	21.3	16.3
8				59.7	66.9	10.3	10.3
9				59.2	54.2	30.6	25.9
10	0.080a	0.28	1.0	65.6	58.2	32.3	32.1
11	0.083	0.18	1.67	76.2	71.5	16.5	15.7
12	0.189	0.26	7.0	61.9	55.5	33.7	38.6
13	0.172	0.19	11.0	79.8	72.9	44.4	46.6
14	0.117	0.24	1.0	35.4	34.6	25.2	25.2
15	0.052	0.14	1.0	87.9	91.0	11.4	10.2
16*	0.103	0.14	8.0	58.9	73.1	22.6	21.7
17	0.090	0.11	8.0	38.3	34.1	24.5	24.0
18	0.088	0.14	3.0	35.8	42.9	34.0	29.3
19	0.190b	0.43	2.33	46.6	63.8	23.0	31.7
20	0.640c	0.75	1.33	85.0	96.5	39.6	48.3
21				100.8	114.2	68.7	37.7
22				43.0	35.0	60.0	52.6
Total, June 7-22				961.0	996.0	498.1	466.2
Net assimilation, June 7-22				462.9	529.8		
Total assimilation, June 7-17				649.8	643.6	272.8	266.6
Net assimilation, June 7-17				377.0	377.0		
Total assimilation, June 18-22				311.2	352.4	225.3	199.6
Net assimilation, June 18-22				85.9	152.8		

a. Sulphur dioxide treatment began at 2.15 p.m. June 10.

b. Sulphur dioxide treatment stopped at 3.40 p.m. June 19.

c. Plants treated with sulphur dioxide for 5.33 hr. from 9.00 a.m. to 2.20 p.m., June 20.

* Marginal and chlorotic discolorations were first noted on June 16. At end of experiment 25% of leaves were marked by sulphur dioxide and 13% completely injured.

absorbed by the fumigated plants. The comparative figures for the total assimilation during the period June 10-14 for Plots B-1 and A-2 are 318.9 and 292.7 gm., respectively, and for the night respiration 152.1 and 158.2 gm. respectively. On June 15 the plot differences were small, but from June 16 onwards Plot B-1 suffered a definite reduction in carbon dioxide assimilation.

The observed lowering of the rate of photosynthesis on June 16 coincides very closely with the appearance of visible injury; the actual symptoms, consisting of marginal markings and chlorotic discolorations, being clearly visible on June 17. Fresh symptoms of sulphur dioxide injury were noted on June 19 and 20, the total number of leaves marked by sulphur dioxide at the end of this experiment being about 25%, and the total injured leaves 13%. Carbon dioxide measurements were not continued after June 22, since the plants were approaching maturity.

The analysis of the carbon dioxide data given in Table XIX shows that the net assimilation during the period June 7 to 17 was equal for both plots, while the net assimilation for the period June 7 to 22 shows a reduction of about 13% in the case of the fumigated plants. The results indicate that during the period when the sulphur dioxide gas had no destructive effect on the leaf tissue the photosynthesis was actually increased.

Continuous Treatment with 0.17 p.p.m. for 66 Hours

Owing to the interesting nature of the results obtained with experiments in the range of concentrations between 0.10 and 0.20 p.p.m. indicating stimulation of photosynthetic activity whenever the sulphur dioxide treatment was unaccompanied by an appreciable amount of leaf destruction, it was decided in 1937 to investigate further the effects of such concentrations.

An experiment was, therefore, carried out on Plots G-4 and H-5 from June 20 to 25, 1937. Carbon dioxide exchange measurements were obtained for about three days prior to the sulphur dioxide treatment of G-4. From 4.00 p.m. on June 22 to 10.00 a.m. on June 25 the plants were fumigated continuously at an average concentration of 0.17 p.p.m.; the plants were half-grown at the time of the experiment, being about 18 to 20 in. in height, and in excellent condition. The total apparent assimilation, as shown in Table XX, of Plot G-4, in comparison with H-5, prior to the sulphur dioxide treatment was 99.3%, and the total night respiration over the same period 114%. During the sulphur dioxide treatment the assimilation ratio of the treated plot over the control rose to 108%, and the respiration dropped to 103%. This indicates again some stimulation of the photosynthetic process during the presence of sulphur dioxide in this range of concentration.

TABLE XX

EFFECT OF SULPHUR DIOXIDE ON CARBON DIOXIDE EXCHANGE OF ALFALFA

Sulphur dioxide treatment from 4.00 p.m., June 22, to 10.00 a.m.,
June 25, 66 hr. with 0.17 p.p.m.

Date 1937	CO ₂ assimilated daily, gm.		CO ₂ respired nightly, gm.	
	Fumigated plot G-4	Control plot H-5	Fumigated plot G-4	Control plot H-5
June 20	144.68	147.65	44.73	36.78
21	129.16	127.23	40.36	37.47
22	90.28	92.38	3.35	3.35
23	69.40	72.18	21.49	17.83
24	80.84	70.79	6.22	9.77
25	31.70	25.48	3.59	2.74
Total June 20-25 -----	546.0	535.6	119.7	107.9
Ratio treated over control, % -----	102		110	
Net assimilation, June 20-25 -----	426.3	427.7		
Total prior to SO ₂ treatment -----	364.1	367.2	88.4	77.6
Ratio treated over control, % -----	99.3		114	
Net assimilation prior to SO ₂ treatment	275.7	289.6		
Total during SO ₂ treatment -----	181.9	168.4	31.3	30.3
Ratio treated over control, % -----	108		103	
Net assimilation during SO ₂ treatment	150.6	138.1		

Fumigated plants were not visibly injured.

Discussion

The experimental fumigation studies described in this section have shown in detail the effect of a wide range of sulphur dioxide concentrations on the photosynthesis and respiration of alfalfa. The behavior of this species may be taken as typical of the reaction of the most susceptible plants to this gas. Many of the experiments have been carried out under such conditions of fumigation that either no visible markings were produced on the leaves or the symptoms were inappreciable, so that the results have a direct bearing on the question of invisible injury. It has been shown by yield studies in a preceding section that sulphur dioxide does not reduce the yield of crop if the concentrations during treatment are maintained below the point at which there is appreciable destruction of leaf tissue. This was found to apply not only in the case of relatively short treatments with high concentrations of gas, but also in prolonged fumi-

gations with low concentrations, the plants in some instances being treated continuously throughout the growth of a crop.

The rate of carbon dioxide exchange is undoubtedly a more sensitive indicator of plant activity than the yield, since it enables one to detect minute differences in behavior which it would be impossible to determine by yield studies. Thus, under experimental conditions, where the rate of carbon dioxide exchange may be measured continuously, detrimental or beneficial effects of sulphur dioxide exposure may be evaluated with a high degree of accuracy. Whenever the exposure results in injuries to the leaf tissue, the photosynthesis is instantly reduced and the respiration increased. This effect will persist for a certain period after the gas has been removed from the atmosphere surrounding the plants, until such time as new leaves replace the injured tissue. Of greater interest, however, is the effect on photosynthesis of high concentrations of gas when the time of exposure is insufficient to produce visible markings, or when the markings are only slight in character. Thus the presence of a concentration of 7.0 p.p.m. for only a few minutes will result in a great decrease in photosynthesis. Similar effects may be obtained with exposures of one hour's duration or less with concentrations of 1.25 to 2.65 p.p.m. In the case of such treatments carried out in daylight, it has been found that the subsequent night respiration is increased. On the other hand, when these high concentrations are present during darkness the respiration is reduced during the presence of the gas, but increases subsequently.

In the absence of visible symptoms the point at which sulphur dioxide begins to exert a perceptible effect on photosynthesis is in the neighborhood of 0.40 to 0.50 p.p.m. Fumigations of several hours each day with concentrations of 0.25 to 0.35 p.p.m. in direct sunlight had no measurable effect on photosynthesis. With sulphur dioxide exposures of the continuous type there was no reduction in assimilation after twenty-four hours' fumigation with 0.35 p.p.m., but a small decrease was manifest after 36 hr. When the gas was removed there was a rapid recovery in the carbon dioxide assimilation to normal levels. In darkness, short treatments with concentrations as high as 0.48 p.p.m. are without effect on the respiration.

The behavior of plants under the influence of sulphur dioxide concentrations of 0.16 to 0.18 p.p.m. is of great interest in that the results point to a small but definite stimulation of photosynthesis. On the other hand, when the concentration is lowered to 0.10 p.p.m. or less there is no evidence of stimulation, but such concentrations, even when maintained throughout the entire growth of a crop, do not affect adversely the net carbon dioxide balance.

From the results of this work, sulphur dioxide concentrations up to approximately 0.50 p.p.m. may be present in the atmosphere of agricultural areas and not prove detrimental to vegetation as long as the environmental and other plant factors are not so abnormal as to induce appreciable leaf injury at these

concentrations. In fact, within the range of 0.10 to 0.20 p.p.m. such low concentrations may actually exert a beneficial effect under ordinary atmospheric humidity conditions. Even when concentrations of the magnitude of 0.50 p.p.m. are present the effect on photosynthesis is only temporary and very much like that of a passing cloud causing a sudden drop in light intensity, unless the exposure is prolonged sufficiently to injure the leaf tissue. At higher levels of gas concentration the absorption of sulphur dioxide by the leaves proceeds so rapidly that injurious effects on the tissue are soon noticeable, particularly when the stomata are open and the soil moisture, light and humidity are high. Concentrations in excess of 0.50 p.p.m. should be limited to periods of darkness, low humidity, drought and low temperature.

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CHAPTER XVI

SUMMARY

BY MORRIS KATZ AND F. E. LATHE

PART I—FIELD STUDIES

Chapter I. Introduction

The Trail smelter smoke investigation arose out of complaints made by farmers of northern Stevens County, Washington, that fumes from the Trail smelter, situated in the Columbia River valley in British Columbia a few miles north of the International Boundary, were damaging their crops and forests. The investigation was carried out for the Canadian Government by the National Research Council and reports were made to the International Joint Commission and to an International Tribunal later appointed to settle the case. The results, now for the first time made generally available, include not only much of the evidence presented to those bodies, but also considerable information of scientific interest which had little or no bearing upon the question of compensation for damages.

Although the Trail smelter is one of the great non-ferrous metallurgical plants of the world, the amount of sulphur dioxide voided to the atmosphere as a result of its operations has not, during any year, averaged more than 665 tons per day, which figure was reached in 1930. Since then there has been a major decrease in gas evolution as a result of remedial measures adopted by the smelting company, involving the erection, at a cost of about fifteen million dollars, of plants for the manufacture of sulphuric acid and fertilizers and the recovery of elemental sulphur.

The investigation of injury from sulphur dioxide was at first limited to surveys of field conditions in the area subjected to visitations of sulphur dioxide gas, but as time went on its scope was enlarged to include experimental work dealing with the effect of sulphur dioxide on plants in order to elucidate problems arising from conditions found in the area.

Automatic sulphur dioxide recorders placed at strategic points gave a continuous record of the length and severity of gas visitations. Surveys of the sulphur content of vegetation were made. In addition, studies were made of the hydrogen ion concentration, base exchange capacity and sulphate content of soils, and the hydrogen ion concentration and sulphate content of water supplies at various distances from Trail. Observations were made on field crops, forests and orchards, and also studies of diameter increment of the more important conifers. This work was supplemented by the experimental fumigation outside the area of crop plants and conifers.

Chapter II. Sulphur Dioxide in Industrial Areas

In many industrial areas the discharge of waste gases containing sulphur dioxide is recognized as an acute problem. This has led to various remedial measures, including the erection of high stacks, operation according to weather conditions most favorable for dilution, heating the stack gases, removal of the sulphur by alkali scrubbers, and, wherever economically feasible, its recovery as liquid sulphur dioxide, elemental sulphur or sulphuric acid.

Appreciable sulphur dioxide concentrations have been found in all industrial areas which have been the subject of recent investigations, the gas being reported in the atmosphere at points within a radius of 25 to 30 miles of many of the larger cities in the United States. The incidence of high concentrations is associated with the presence of fog, low wind velocity, high humidity and the absence of a temperature gradient.

The rapid expansion in operations of the smelter at Trail, B.C., after 1924, led to litigation over damage caused in the adjacent part of Stevens County, Washington. Methods of sulphur recovery were instituted at the smelter in 1931, with the erection of sulphuric acid units with a total daily capacity of 375 tons. Subsequently, in 1936 and 1937, large absorption and reduction plants were erected for the recovery of elemental sulphur.

From the investigation of atmospheric conditions over the eight-year period, 1930 to 1937, a clear-cut picture has been obtained of the character, frequency and intensity of the sulphur dioxide visitations in this area. These visitations are governed by the topography of the Columbia River valley, and also by the velocity and persistence of the prevailing surface winds and upper air currents.

Simultaneous observations at three recorder stations have shown a large decrease in average and maximum gas concentrations, with distance, in the region 6 to 20 miles south of Trail. The results indicate a drop of about 70% in the average gas concentration and a further dilution of a much smaller order at more remote points south.

The spread of the gas is severely restricted by the mountainous character of the narrow Columbia valley, and at only a few points can sulphur dioxide in normal circumstances spread laterally in the tributary valleys, such as those of Deep and Sheep Creeks. The concentrations found at points several miles up these creeks are generally much lower than those in the main valley of the Columbia at equal distances from the smelter. Broadly speaking, the frequency with which sulphur dioxide occurs and the magnitude of the concentrations found in the main valley from Trail to the vicinity of Northport (20 miles south of Trail) and from south of Northport to Bossburg (37 miles

south of Trail) are noticeably different, and can conveniently be distinguished as the first and second zone respectively. The maximum concentration found in this first zone at the Stroh recorder station (15 miles south of Trail) in 1930 was 2.11 p.p.m. During the same year the maximum concentration recorded near Marble (30 miles south of Trail) in this second zone was 0.93 p.p.m. At the Stroh recorder station the highest monthly average of all determinations, including zero, during 1930, was 0.115 p.p.m., and at the Marble recorder, 0.080 p.p.m.

Since 1931 the number of readings of concentrations in the atmosphere in excess of 0.10 p.p.m. has been greatly reduced during the summer months, and concentrations above 0.50 p.p.m. practically eliminated at points 15 miles south of Trail and beyond. During some of the winter months, in the years since 1931, the meteorological conditions have been unfavorable for the diffusion of the gas, and consequently sulphur dioxide has been found to persist in the atmosphere continuously for days, or even weeks.

In the growing seasons since 1931 the maximum concentration found at the Stroh recorder was 1.30 p.p.m. (April, 1933) while the highest monthly average of all readings was 0.033 p.p.m. During the growing season of 1937 the maximum concentration was 0.48 p.p.m. and the highest monthly average of all readings, 0.0197 p.p.m.

The gas conditions in this area since 1932 have been improved to the point where they may no longer be considered to be damaging to vegetation. The maximum and average concentrations at points 15 and 20 miles south of Trail are now considerably lower than those found in many other smelter and urban areas.

Chapter III. Symptoms and Diagnosis of Injury to Plants

Sulphur dioxide produces characteristic symptoms on the leaves of plants which are generally classified under the broad headings of acute and chronic injury. Accurate diagnosis of the distribution and degree of such injury is, however, a difficult matter unless some knowledge is available of the character and intensity of the sulphur dioxide visitations, the meteorological conditions, the sulphur content of the affected plants and the reaction of indicator plants. Numerous markings closely resembling those of sulphur dioxide may be attributable to other causes, such as winter injury, drought, insects, fungi and various physiological disorders. The careful investigator must, therefore, utilize as aids in the diagnosis and estimation of the amount of injury present, such knowledge as may be afforded by a study of the factors enumerated above.

Within the Columbia River valley in the area affected by the operations of the Trail smelter, the forest is essentially coniferous. At lower elevations in this valley the most common species are yellow pine, lodgepole pine, Douglas fir and larch. Spruce, grand fir, white pine and cedar occur to a limited extent at higher elevations. The more important broad-leaved trees of the area are paper birch, mountain alder, maple, aspen and black cottonwood. A number of shrubs also serve as useful indicator plants, particularly ninebark and ocean spray. The area immediately adjoining the Trail smelter area has been denuded of the native grasses and conifers, although a few hardy shrubs and some broad-leaved trees are still present. Conifers begin to make their appearance at a distance of about 12 to 15 miles from the smelter. Douglas fir has been most severely affected in comparison with other species. A few more resistant yellow pine and larch have managed to survive in the area where the fir has been killed.

Susceptible species, such as larch, ninebark and alfalfa, are injured by sulphur dioxide most frequently in the early part of the growing season, in May and June,—at such times when the gas visitations coincide with periods of high humidity. During July and August when the temperatures are high and the humidity and soil moisture relatively low, sulphur dioxide markings are seldom found. In September, when soil moisture and humidity conditions are higher, alfalfa and other susceptible plants, including apple leaves, are liable to be injured. Larch is the most susceptible species in early May, and in several seasons was injured at this time of the year for a distance of about 30 miles south of Trail.

Acute symptoms of sulphur dioxide injury to crop plants are seldom present when the rainfall is deficient. Field observations indicate that acute symptoms of injury are generally associated with the period of the year most favorable for growth. Among the most susceptible crop plants may be listed alfalfa, barley, rye, wheat and oats. Plots of these species were maintained for several years at a point 15 miles south of Trail, near the site of an automatic sulphur dioxide recorder. It was thus possible to correlate the known sulphur dioxide visitations with the observed symptoms on the plants.

The symptoms of acute injury to conifers consist of a reddish discoloration of the leaves, with a subsequent shrinkage of tissue and defoliation. The discolorations may involve the whole length of the leaf or only a limited area at the base, middle or tip. The effect of such injury, if repeated with sufficient frequency, is to reduce the number of years' leaves on the affected tree. Where the gas concentrations are of lower intensity, the injury is of the chronic type, consisting of a partial destruction of the chlorophyll with consequent chlorosis or yellowing of the affected tissues.

The symptoms of injury on crop plants may be classified under the headings of acute and chlorotic. In the case of cereals, acute injury may be further subdivided into the concentrated type, which consists of a complete killing of the tissue for a definite distance from the tip of the leaf, the mottled or spotted type, and the banded type. The first symptoms of acute injury consist of slightly flaccid areas of a diffuse, greyish-green coloration. In the presence of sunlight a rapid desiccation of the affected area takes place, accompanied by a great shrinkage of the cell contents, the leaf assuming a bleached appearance after the decomposition of the chlorophyll.

Chlorotic injury which consists in a loss of the normal green color of the chlorophyll is of two types, involving either temporary or permanent effects. In the case of the temporary type the leaves do not lose their turgor even though the color is subnormal. Under suitable conditions the affected plants may recover from this state.

In the case of alfalfa, whereas the symptoms of injury may be divided into the two classes of acute and chlorotic, the acute type may be marginal, concentrated intercostal, diffuse intercostal, or veinal. In the incipient injury stage, the cells lose their capacity to retain water, the cell sap permeating the intercellular spaces and imparting a water-soaked appearance to the affected area. This flaccid area then dries out quickly in sunlight and after complete desiccation the injured tissue becomes ivory white.

Chlorotic symptoms in alfalfa may also be subdivided into the two types, transient and permanent. The transient type of chlorosis may be readily overlooked unless control plants are available for comparison. The permanent type results in a yellow to yellowish-brown condition of the leaves, closely simulating senescence.

The effect of sulphur dioxide on the internal structure of the alfalfa leaf has been studied by the use of prepared sections of treated and untreated specimens. Leaves treated with high concentrations of sulphur dioxide show a marked shrinkage of tissue, this internal shrinkage being manifest, particularly in the palisade cells even in those cases where there were no external symptoms. In the case of prolonged treatment with low concentrations of the gas, there were no clear-cut differences between treated and untreated leaves, nor was there any evidence of the presence of dead cells. There was only a detectable difference in the staining reaction of these leaves when treated with safranine.

Chapter IV. The Sulphur Content of Vegetation

The sulphur content of the leaves of plants exposed to sulphur dioxide has been found to increase substantially over a period of time. A definite cor-

relation exists between the sulphur content of vegetation and sulphur dioxide in the atmosphere. Although there is no quantitative relation between the increase in total sulphur content of the leaves and the degree of injury, it is nevertheless possible through comprehensive collections of foliage, to define the areas within which this gas occurs.

The distribution of sulphur dioxide in the atmosphere south of Trail, B.C., has been studied through the examination of the sulphur content of vegetation in the Columbia River valley, and its tributaries, in comparison with similar species from areas outside the smoke zone. In 1930-31 the area in which sulphur dioxide could be detected by this means extended 58 to 62 miles south of the smelter in the main Columbia valley, but not more than six to eight miles away from the Columbia River in the tributary valleys between the International Boundary and Northport. In 1934 the lower limit of this area in the main valley had receded to the vicinity of Bossburg-Evans, 39 to 43 miles south of Trail, whereas in the tributary valleys there was no sulphur dioxide effect more than three miles from the Columbia River. The results also showed a marked decrease in the sulphur content of the vegetation compared with the 1930-31 collections at corresponding points.

The 1935 studies indicate a somewhat more extensive distribution of sulphur dioxide than in the preceding year as a result of an increase of approximately 35% in the total duration of gas occurrence during this growing season. In 1936, on the other hand, the sulphur content of yellow pine and Douglas fir was lower at corresponding points than in 1935, owing to a reduction in the duration of the gas visitations.

Conifers have been shown to accumulate sulphur from the atmosphere rapidly in young leaves and more gradually in older leaves over a period of years. This absorption takes place for the most part during the growing season. During the winter months of December, January and February, Douglas fir shows no significant absorption of sulphur dioxide, notwithstanding the presence of gas for longer periods and in higher concentrations than during the summer. Yellow pine, on the other hand, shows a slight increase in the sulphur content of its leaves over the winter period. This pronounced decrease in absorption during the winter is accounted for by the greatly reduced physiological activity of the leaves. Studies of the sulphur content of conifers at different elevations in the main path of the smoke in the Columbia River valley indicate that the maximum elevation at which the effect of sulphur dioxide can be detected is in the neighborhood of 3,750 ft. above sea level, or approximately 2,500 ft. above the river.

The accumulation of sulphur in the leaves of vegetation may reach values three or four times greater than normal without any noticeable effect on the color of the foliage and, in the case of conifers, without any measurable

retardation in growth. Within the limit of tolerance of a given species for sulphur the rate at which a given amount of sulphur is accumulated is of much greater significance in relation to injury than the actual amount. In areas where the gas concentrations are low the absorption of sulphur dioxide by foliage is usually an innocuous process.

Chapter V. The Effect of Sulphur Dioxide on Soils

The soils in most industrial regions have been exposed to the action of sulphur dioxide for many years. This gas may be absorbed directly by the soil or may reach it indirectly through absorption by vegetation or atmospheric precipitation. If absorbed directly, the sulphur dioxide is oxidized to sulphuric acid, the acid then reacting with the bases in the soil to form sulphates. The greater part of the sulphur added to the soil by indirect absorption is also in the form of sulphate. This process also tends to increase the acidity and decrease the base saturation and may involve a gradual loss of calcium, magnesium and other bases.

Investigations of cultivated soils have shown that the effects of prolonged exposure to smoke are negligible. Even in virgin soils such effects are slight in the case of the more highly buffered types of soil. On poorly buffered virgin soils, however, exposure to sulphur dioxide for many years may result in an increase in acidity and depletion of the bases. In abnormal cases the accumulation of sulphuric acid may result in an adverse effect on the activity of the micro-organisms in the soil and on the decomposition of the surface organic layer.

However, sulphur is one of the essential elements necessary for the growth of crops, and in many regions its removal by crops and natural leaching processes is so rapid as to cause depletion within a few years, with a resultant loss in crop yield. In this respect, therefore, additions of sulphur through absorption from the atmosphere may be regarded as beneficial.

In the present investigation the soils of the Trail-Northport area, which have been exposed to fumes from Trail, B.C., since 1896 and from a smelter operated at the town of Northport, during the periods 1896-1908 and 1916-1921, have been examined in order to determine whether there has been an injurious effect. The work was confined to virgin soils, mainly of the glacial lake and river terraces, consisting of sands and sandy loams, silts and clays, within the main valley of the Columbia River at various distances from Trail. Such soils have generally a low buffer capacity and are therefore sensitive to the action of sulphur dioxide.

The results indicate that within an area extending about six to eight miles north or south of Trail there is a marked increase in the acidity, a decrease

in base saturation, and an increase in sulphate content. This effect diminishes rapidly with increasing distance, and becomes negligible at about 10 or 12 miles from the smelter, with the exception of a limited area on the west side of the Columbia River about two miles south of the International Boundary. Within this limited area the Mission soil, a low buffered, sandy type, showed abnormally low values for base exchange capacity and a high acidity, whereas the more highly buffered types were not appreciably affected.

Chapter VI. The Effect of Sulphur Dioxide on Water Supplies

The investigation of the sulphate content and hydrogen ion concentration of the water supplies of the Columbia River valley and its tributaries was undertaken to supplement the work on soils. Water samples were collected from many springs, creeks, lakes and wells over a considerable area, not only within the so-called smoke zone, but in many areas outside the range of any possible smoke influence. As both the sedimentary rocks and granites of this highly mineralized area may contain sulphur associated with minerals, the sulphate content of the water supplies was examined in its relation to the known formations as determined by the official geological surveys of Stevens County, Washington. Water supplies were classified into those arising directly from sand benches or other glacial material and those coming from the parent rock and unconsolidated material.

Within a restricted area north and south of Trail, the creeks showed an increase in sulphate content traceable to the operations of the Trail smelter. Springs rising in sand benches near Trail had a higher sulphate content than those at a distance. Except as indicated above, there was no correlation between the location of the water supplies with respect to the smelter and their sulphate content.

The influence of parent material was clearly indicated, both by the sulphate content and by the hydrogen ion concentration of these waters. The high sulphate values were found to be associated with springs and creeks flowing through such sedimentary rocks as the argillites. Waters seeping through pure white limestone were extremely low in sulphates, while those coming from the granite were of intermediate sulphate content.

Chapter VII. The Diameter Increment of Conifers

Studies of diameter increment were carried out in 1929, 1930, 1934 and 1936, the method being to take borings from the trees and measure the width of the annual rings. The investigation included Douglas fir in all four years, yellow pine in the first three years and lodgepole pine in 1929 only; the later investigations were required to determine the effect of remedial measures adopted at the Trail smelter, as well as that of more favorable precipitation.

In the four years 10,043 trees were bored and more than 175,000 measurements were made on the cores obtained.

In order to secure a representative sample and to eliminate the personal factor in the selection of trees to be bored, the method adopted was to bore all living trees of suitable size in a given locality, rejecting only those obviously fire-scarred or otherwise unsuitable for comparison. Except when a sufficient number of trees was not available, at least 100 trees were bored in any group selected, that number being found sufficient to mask individual variations.

Precipitation from January to August, inclusive, proved to be the chief factor influencing the growth in northern Stevens County of trees unaffected by sulphur dioxide. Good correlation was found between precipitation and diameter increment during the period 1915 to 1936; the lack of a precipitation effect at any time was interpreted as an indication of the influence of some other factor limiting tree growth, such as sulphur dioxide.

The absolute rate of growth of groups of trees chosen as controls was found to vary as much as 200%, but with one exception their growth trends were very similar. Trends only were considered in the interpretation of the growth of trees affected by sulphur dioxide.

In the area in the Columbia Valley from 12 to 15 miles south of the Trail smelter, yellow pine trees showed a large deviation in growth trend as compared with the controls during the period of maximum sulphur dioxide emission from the Trail smelter, and smaller deviations coincident with the earlier operation of the Northport and Trail smelters. There was, however, a complete recovery by 1932. From 15 to 25 miles south of Trail, near Northport, yellow pine trees showed a greater effect from the operation of the Northport smelter than did those near the Boundary, and a smaller effect from the smelter at Trail. Trees 28 to 30 miles from Trail did not show any effect from the operation of the Northport smelter, and were perceptibly retarded during only two years of maximum sulphur dioxide emission from the Trail plant; at this point precipitation was the major factor affecting tree growth during the whole period. The effect of the operations of the Trail smelter reached the vanishing point at a distance of about 40 miles from the source. Following the adoption of remedial measures at the smelter, all these groups of yellow pine trees showed a trend of growth rather more favorable than that of the controls; the possibility of slight stimulation from the action of sulphur dioxide therefore cannot be wholly disregarded.

Douglas fir groups were bored over a larger area than those of yellow pine. Trees growing within seven miles of the International Boundary in the Columbia River valley were reduced more than 50% in the rate of growth

during the period of maximum sulphur dioxide emission from Trail, and even by 1936 showed incomplete recovery. Trees farther down the river and for short distances up tributary creeks were moderately affected by the action of sulphur dioxide, followed by complete recovery. The effect of the operation of the Northport smelter was similar to that observed for yellow pine.

Young lodgepole pine trees showed an effect from the operation of the two smelters similar to that observed for Douglas fir and yellow pine, but a moderate rate of growth was nevertheless maintained throughout the whole period.

The conifers made the subject of this study showed the following decreasing order of sensitivity to sulphur dioxide:—Douglas fir, yellow pine, lodgepole pine.

In general, it may be said that the picture presented by the diameter increment studies on conifers is a consistent one, quite in harmony with field observations on trees, shrubs and field crops in the same area, as well as with the sulphur content of the needles of conifers and the percentage of sulphur dioxide in the atmosphere.

PART II—FUMIGATION EXPERIMENTS

Chapter VIII. Description of Plots and Apparatus

For a description of plots and apparatus the reader is referred to the text in Chapter VIII.

Chapter IX. Conifers in Natural Habitat

Sulphur dioxide fumigation experiments on a natural stand of reproduction of Douglas fir and yellow pine indicate the susceptibility of these species to specific sulphur dioxide concentrations, the seasonal variation in susceptibility and the relation between extent of absorption and injury. About 420 trees in 40 plots were subjected to sulphur dioxide treatment under controlled conditions. The plots were enclosed in gas-tight cabinets covered with a celluloid material which allowed free access to light. Air mixed with sulphur dioxide was passed through these cabinets at a rate sufficient to provide for the normal carbon dioxide requirements of the trees. The trees varied in age from seedlings a few years old to those about 25 to 30 years. Continuous measurements were made of the sulphur dioxide concentrations in the air entering and leaving the cabinets. The experiments were carried out continuously during the period, January to September, 1931.

During the winter period conifers are extremely resistant to sulphur dioxide and are injured only after prolonged treatment at high concentrations. The trees show a marked change in susceptibility in the early spring, coincident with the termination of the period of winter dormancy. From the early spring until about midsummer there is little change in susceptibility. Treatment with 5.0 p.p.m. for as long as 96 hours produced only slight sulphur dioxide markings on a few leaves during February, whereas in March treatment for only 45 hours resulted in very severe injury, and in June and early July similar injurious effects were obtained after 19 to 40 hours of fumigation. Even at the period of maximum susceptibility the conifers showed no ill effects after prolonged treatment with low concentrations, 0.25 p.p.m. being maintained without injury for as long as 450 hours during April and May. In the late summer and autumn conifers become increasingly resistant to sulphur dioxide. At this time of the year the trees could be treated with 0.50 p.p.m. for approximately 1000 hours without injury, whereas in the early spring symptoms of incipient injury appeared after 336 hours.

Studies of the absorption of sulphur dioxide by the leaves of conifers indicate that the rate of absorption rather than the actual amount of sulphur accumulated in the foliage is the most important factor in determining the degree of injury. Whenever the experimental and environmental conditions favored a rapid rate of absorption, the leaves were invariably injured. In low concentration experiments, where the sulphur accumulated slowly over a long period, the leaves remained uninjured, even though the total at the end of the treatment was considerably higher than that found in the high concentration experiments.

A considerable residual effect on the growth of the trees is shown in the case of injurious sulphur dioxide treatments. Trees containing a considerable proportion of injured leaves were found three years later to carry only a scanty growth of foliage. In those cases where the fumigated trees were severely injured, a partial killing of the limbs had occurred and the leaves put out subsequently were confined principally to the interior of the tree, the main stem and the inner portions of the branches. Along the main stem and on the adjacent parts of the limbs there was a noticeable development of adventitious buds. In only a few instances were trees found to be actually killed by sulphur dioxide.

Studies were made of the height growth of the fumigated trees during the period 1928-1935 in comparison with controls. The fumigated trees were divided into two groups i.e., trees in which 0-10% of the foliage had been injured and trees showing 20-100% leaf injury. In the case of the slightly injured group, a small adverse effect upon growth was noticeable in the years 1933-34. For the severely injured group the growth rate showed a consider-

able reduction from 1931 onwards, but the relative, as distinguished from the absolute, rate of growth had, by 1935, improved to the point where it was substantially the same as that of the controls.

Chapter X. Experiments on Transplanted Conifers

In the autumn of 1935 and the summer of 1936, fumigation experiments were carried out on conifers which had been established in the preceding autumn and spring. The plots consisted of Douglas fir, white pine, yellow pine, lodgepole pine, Sitka and Engelmann spruce, and larch. There were only a few silver fir, white fir and hemlock, since it was found extremely difficult to transplant seedlings of these species. The age of the trees varied from three to ten years. In the summer of 1937 a limited number of experiments were also carried out on young yellow pine and Douglas fir seedlings.

Like the conifers in natural habitat, the transplanted conifers were found to show a seasonal variation in susceptibility. Concentrations and exposures which were injurious during the period of active growth, in the summer, were relatively innocuous in the autumn and winter.

Larch was found to be the most susceptible of the conifers during the period of active growth. At an average relative humidity of 67%, in daylight, the larch were injured after eight hours' fumigation at an average concentration of 0.30 p.p.m. in May. This indicates a much higher order of susceptibility than that of either Douglas fir or yellow pine.

Young seedlings of yellow pine and Douglas fir were found to be very susceptible to sulphur dioxide, and under the conditions favorable for rapid growth were injured after eight or nine hours' exposure to concentrations of 0.50 to 0.75 p.p.m. Concentrations of 1.0 p.p.m. or higher were extremely injurious when prolonged for 15 hours or more. Under such conditions very young seedlings showed a considerable rate of mortality.

The results indicate that transplanted conifers grown in irrigated plots are definitely more susceptible to sulphur dioxide than similar species growing under natural conditions. This may be due to either the more vigorous growth of the latter or the higher leaf turgor of the transplanted stock. The order of susceptibility of the various coniferous species was as follows: larch, Douglas fir, Engelmann spruce, white pine, yellow pine, cedar, lodgepole pine, silver fir and white fir.

Chapter XI. Environmental Factors and Susceptibility

The environment of the plant exerts a marked influence on its susceptibility to sulphur dioxide. Thus it has been observed in the field that plants are more liable to injury during daylight than at night and that the toxicity of

the gas increases with a rise in temperature, light intensity and humidity. Relatively high concentrations must be present in order to injure susceptible plants during darkness, or even in daylight under low atmospheric humidity conditions. The most important factors which govern the extent of leaf injury are the concentration, duration of exposure, relative humidity, light intensity, temperature, soil moisture and age of the plant. Certain internal leaf factors are also important in their bearing on the rate of absorption of gas. Among these may be mentioned the movement of the stomata and the leaf turgor.

With regard to the influence of concentration-time factors, studies of such highly susceptible plants as barley and alfalfa indicate that the time of exposure for incipient injury decreases quite rapidly with increasing concentrations in the range of 0.30 to 2.0 p.p.m. Under average growth and normal humidity conditions these plants may be injured after only a few hours' exposure to concentrations of 1.0 p.p.m. or higher, whereas concentrations of about 0.15 p.p.m. or lower may be tolerated throughout the growth of the crop without injury. A rise in relative humidity, particularly in the range above 60-70%, results in a considerable increase in susceptibility. However, when the concentration is sufficiently high, the time of exposure for injury becomes so brief that the relative humidity is then only a minor factor in its influence on susceptibility.

Experiments on the effect of light at definite intensities indicate that the influence of this factor is greatest in the range up to about 3000 foot-candles. At higher light intensities the susceptibility increases only slightly with rise in light intensity. The effect of light is interrelated with that of other factors which govern the movement of the stomata, the physiological activity of the plant and consequently the rate of absorption of sulphur dioxide.

Injury to leaves invariably follows exposure to high concentrations under conditions of relatively high rates of absorption, i.e., when the stomata are fully open, the leaf turgor is high and the photosynthesis is at a maximum. Experiments with barley and alfalfa show that the rate of absorption of gas by the leaves under normal growth conditions reaches a maximum during the period of the day between eight a.m. and two p.m. Thereafter the rate diminishes, reaching its lowest level during night respiration. An increase is again manifest in the early morning hours, coincident with the change from respiration to photosynthesis. Any change in environment which induces a partial or complete closure of the stomata or a reduction in leaf turgor decreases the rate of absorption.

With regard to the influence of age, cereals are most susceptible in the early leaf stage and most resistant in the cotyledon and head stages of growth. After the cotyledons have developed there is not much difference

in susceptibility during the period of active leaf production up to the shot-blade stage. In alfalfa, there is not much difference in susceptibility over the period of growth from about a week after the previous cutting until the early flower stage. However, young seedlings at the cotyledon stage are extremely resistant to sulphur dioxide. Plants in the late flower stage are also comparatively resistant.

The middle aged leaves of crop plants in the pre-flowering period are more susceptible than the younger and older leaves. Senescent leaves are the least susceptible. Buds and rapidly expanding leaves are seldom affected by sulphur dioxide.

Variations in soil moisture over a considerable range do not appreciably affect the susceptibility of plants until the wilting-point of the soil is approached. At this point plants undergo a profound change in susceptibility, particularly where the effects of drought are sufficient to produce stomatal closure. The resistance of plants under these conditions is so marked that sulphur dioxide is relatively non-toxic except in high concentration.

Fumigation experiments with plants grown in cabinets indicate that their response to sulphur dioxide is not essentially different from that of plants grown under natural conditions where the gas concentrations, times of exposure and other factors are similar.

Chapter XII. Stomatal Behavior of Alfalfa

The influence of definite concentrations of sulphur dioxide on the stomatal movement of alfalfa leaves has been investigated by various methods, such as direct microscopic measurements, measurements of epidermal strips from leaves preserved in absolute alcohol, and direct observations on the living tissue by means of an automatic porometer method. Various experimental treatments covering the range of concentration between 0.10 and 5.8 p.p.m. were applied. With the highest concentrations there was a marked effect on stomatal movement which induced partial or total stomatal closure within a few minutes after the application of the gas. With decreasing concentration this effect gradually disappeared until, to induce closure of the stomata, it was necessary to prolong exposure to the point where injurious markings appeared on the leaves. Exposures of four hours' duration with concentrations of 0.44 to 0.76 p.p.m. were without effect on stomatal movement. At a concentration of 0.40 p.p.m. there was a slight interference with stomatal function after four days of continuous treatment, coincident with the appearance of chlorotic and acute markings on the leaves.

With concentrations lower than 0.30 p.p.m., no measurable closure of stomata was found, even though the gas was applied for many hours. Con-

tinuous exposure with an average concentration of 0.10 p.p.m. throughout the growth of the crop had no influence on the stomatal movement of alfalfa.

Chapter XIII. Yield of Barley and Alfalfa

The effect of sulphur dioxide treatment on the yield of barley and alfalfa has been studied, with special emphasis on the problem of invisible injury. The yield studies were carried out on a considerable number of specially prepared plots grown under normal conditions as regards temperature, humidity and soil moisture. Yields of the fumigated plots at harvest have been compared with those of adjacent control plots. The yield data have been subjected to statistical analysis and conclusions have been based on the results of as many experiments as possible within a given series.

In the case of barley, experimental fumigations covering a considerable range of sulphur dioxide concentrations indicate that in the absence of visible symptoms of injury or where the resultant injury to the foliage is not greater than about 5%, there is no decrease in the yield of either straw or grain and no effect on tillering or kernel production. The treated plants show a marked ability to recover from the effects of injurious fumigations, and if the extent of the markings involves only a small percentage of the total leaf area, the barley plant appears capable of replacing this loss under normal growing conditions without affecting the yield. With increasing leaf destruction, in the case of fumigations carried out prior to the flowering period, barley shows a much greater reduction in the weight of straw than in that of grain. On the other hand, injurious fumigations during the flowering period indicate little effect on the straw but a considerable reduction in the yield of grain, the decrease in yield of grain being the result of a reduction in the weight of the kernels, but not their number.

With regard to alfalfa, there is no reduction in yield as a result of prolonged treatment with low, non-marking, sulphur dioxide concentrations. In many experiments the alfalfa was exposed continuously to low concentrations, practically throughout the growth of the crop, without any effect on the yield or height development. Alfalfa is more sensitive to slight markings by sulphur dioxide than is barley. Its capacity for recovery from the effects of injurious fumigations is less pronounced and consequently it shows a greater degree of correlation between extent of leaf injury and reduction in yield. The highest reduction in yield is shown by those plots which were subjected to injurious sulphur dioxide treatments during a period from ten days to three weeks after cutting. The least effect is shown by plots injured during the flowering stage. In the case of very injurious sulphur dioxide treatments, involving a high percentage of leaf injury there is not only a reduction in the yield of the current crop but there may also be an effect on the

yield of subsequent crops. However, if the leaf destruction is of the order of only a few per cent there is no residual effect on the yield in the case of single, double or even triple crop fumigations.

No basis in fact has been found for the view expressed by some investigators that sulphur dioxide, in the absence of leaf injury, exerts an invisible effect detrimental to the yield and growth of crops.

Chapter XIV. Effect on Chemical Composition

This phase of the investigation was concerned particularly with the effect, if any, of the abnormal increase in sulphur content of fumigated plants on the protein and carbohydrates of the leaves and grain.

In the case of barley, the leaves of plants treated with average concentrations of 0.27 to 0.34 p.p.m. showed no diminution in protein content notwithstanding a considerable accumulation of sulphur, as long as the leaves remained free from injury. After prolonged treatment, however, coincident with the appearance of a considerable amount of acute and chlorotic markings, there was a reduction in the protein content. The protein, sugar and starch contents of mature barley grain were not affected by exposure of the growing plant to concentrations of 0.27 to 1.0 p.p.m. when the fumigations did not cause visible symptoms on the leaves or resulted in only slight markings. With more injurious sulphur dioxide treatments there was a reduction in the starch content of the grain and a significant correlation between the extent of leaf injury to the plant and decrease in starch content. No significant effect was found on the protein content of the grain in any of the experimental treatments.

Experiments on alfalfa with concentrations of 0.10 to 0.40 p.p.m., the exposures being varied from 112 to 602 hours, indicated abnormally high accumulations of sulphur in the leaves, but no significant differences in moisture, protein and total content of acid-hydrolyzable polysaccharides plus sugars. Even when the concentration was increased to 0.60 p.p.m. there was no significant change in composition. In most of these experiments there was either no injury produced or the extent of the markings was negligible. With high concentrations of sulphur dioxide (approximately 3.0 p.p.m.), a relatively short exposure resulted in a considerable decrease in sucrose and acid-hydrolyzable polysaccharides, in the case of totally injured leaves. In such leaves there was also a marked decrease in moisture content and a percentage increase in protein nitrogen. Leaves which were still apparently normal green after such treatment, showed no appreciable difference in moisture and nitrogen content, but there was a decrease in the amount of polysaccharides.

The sulphur dioxide absorbed by the leaves was converted almost entirely to sulphate in the case of alfalfa plants treated with low concentrations of gas. With increasing concentration, however, small amounts of sulphur dioxide remained unoxidized in the leaves and exerted a destructive action on the tissue. There was a direct correlation between the extent of leaf injury and the amount of sulphur dioxide or sulphurous acid present in the tissues.

Chapter XV. Carbon Dioxide Assimilation and Respiration

It has been generally observed that sulphur dioxide in sufficiently high concentrations exerts a specific action on the photosynthesis of plants. The period of maximum susceptibility occurs usually at the time when the environmental factors are most favorable for a high rate of carbon dioxide assimilation. Plant organs which do not contain or are deficient in chlorophyll are quite resistant to the action of sulphur dioxide. For this reason buds, cotyledons and very young leaves may remain uninjured under conditions where the actively assimilating leaves are totally destroyed.

In contrast to the sensitivity of the photosynthetic mechanism to sulphur dioxide, the process of respiration is not nearly as susceptible to change by this gas. However, in darkness a considerable reduction in respiration has been observed in the presence of abnormally high concentrations.

Of special interest is the effect on photosynthesis during exposure to sulphur dioxide under such conditions that the leaves are not visibly injured. The rate of carbon dioxide assimilation is undoubtedly a more sensitive indicator of plant activity than the yield, and studies of the rate of assimilation reveal small differences in behavior which would not be demonstrable in yield tests. Plants which have been injured by sulphur dioxide show a considerable decrease in photosynthetic activity, the magnitude of the decrease being dependent upon the extent of injury to the leaves. Respiration, particularly in the case of severe damage, is increased. Until recently, however, no conclusive evidence has been available on the effect of fumigations which do not result in visible injury.

Continuous measurements of the rate of carbon dioxide assimilation and respiration of alfalfa by means of a new automatic method have been carried out on specially prepared plots. The rates of photosynthesis and respiration prior to, during, and after the application of sulphur dioxide gas covering a wide range of concentrations, were investigated in comparison with similar untreated plants of equivalent leaf surface subjected to the same environmental conditions. In the absence of visible symptoms, sulphur dioxide began to exert a measurable effect on photosynthesis when the concentration was in the neighborhood of 0.40 to 0.50 p.p.m. Daily exposures of several

hours' duration with concentrations of 0.25 to 0.35 p.p.m. did not change the rate of photosynthesis. With treatments of the continuous type there was no effect after 24 hours' exposure to average concentrations of 0.35 p.p.m., but a temporary decrease was shown after 36 hours. When the leaves were not visibly injured, the carbon dioxide assimilation returned rapidly to the normal level after removal of the gas. Concentrations of approximately 0.10 p.p.m. or lower had no effect on the photosynthesis even when the plants were treated continuously throughout the growth of a crop, and there was no adverse influence on the net carbon dioxide balance. On the other hand, with concentrations in the range of 0.16 to 0.18 p.p.m. there was a slight stimulation of the rate of photosynthesis.

When the concentration was increased beyond 0.40 p.p.m. and the exposures were insufficient to injure the leaves, photosynthesis was reduced during the presence of the gas, but the effect on the chlorophyll mechanism was only temporary in character, similar to that caused by a sudden lowering of the light intensity. When the gas was removed the rate of assimilation returned rapidly to the normal level. With increasing concentration of gas the photosynthesis was sometimes completely inhibited, but even in such cases there was a complete subsequent recovery of the assimilation, although the shock to the chlorophyll mechanism was, in some cases, sufficient to prevent complete recovery for a period of one or two days.

With regard to respiration, short treatments in daylight with high concentrations, which did not result in an appreciable amount of leaf injury, had the effect of increasing the subsequent night respiration. On the other hand, when the treatments were carried out in darkness the respiration sometimes decreased during the presence of the gas but increased subsequently.

Although the results indicated above were based on studies of alfalfa, the behavior of this species may be taken as typical of the reactions of the most susceptible plants to this gas. The influence of high concentrations on photosynthesis has, no doubt, formed the basis for the contentions of proponents of the invisible injury theory. However, yield studies indicate that when plants are exposed to concentrations of this order for times insufficient to injure the leaves, there is no measurable effect on the yield of crop, presumably because there is no permanent effect produced on the chlorophyll or protoplasm of the cells. The observed lowering of the photosynthesis is of such a transitory character and the subsequent recovery is so rapid that the resultant effect on the net carbon dioxide balance for the entire growth period of the crop is negligible. Repeated exposures to high concentrations even of short duration, invariably result in injury, with a consequent reduction in yield. Although it would be theoretically possible to reduce the net carbon dioxide balance and therefore the yield of crop by repeated short exposures

to high concentrations of gas, in actual practice such conditions cannot be imposed without the destruction of a considerable proportion of the leaf surface.

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